A RETROSPECTIVE ASSESSMENT OF CLEAN ENERGY INVESTMENTS IN THE RECOVERY ACT

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EXECUTIVE OFFICE OF THE PRESIDENT OF THE UNITED STATES
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Contents

Executive Summary

President Obama took office in the middle of the worst economic crisis since the Great Depression. In the previous year, private employers shed 3.8 million jobs. Trillions of dollars of household wealth had been wiped out, and the economy's total output, as measured by real gross domestic product (GDP), was in the midst of its most severe downturn of the postwar era. In the face of this crisis, the President took immediate, bold, and effective action.

On February 17, 2009, less than a month into his first term, President Obama signed into law the American Recovery and Reinvestment Act of 2009, also known as the Recovery Act, or ARRA. ARRA was not only a historic action to help bring about a macroeconomic recovery, but it was also a dramatic investment in the future of the U.S. economy. In 2009, there was an initial allocation of $90 billion dollars of ARRA funds towards clean energy-related investments—an unprecedented investment in clean energy and towards a sustainable 21st century economy.

These investments contributed to the recovery—GDP per capita started expanding in the third quarter of 2009 and reached its pre-crisis level in nearly four years. The Council of Economic Advisers (CEA) (2014) estimated that from late 2009 through mid-2011, ARRA lifted GDP 2 to 3 percent above where it would have been, and over 6 million job-years (a full-time job for one year) were supported by ARRA from 2009 to 2012. The clean energy-related funding made up roughly one eighth of the total, representing a substantial direct boost. In this report, CEA estimates that ARRA clean energy-related programs supported roughly 900,000 job-years in innovative clean energy fields from 2009 to 2015.

The short-run effects of ARRA are only half the story. These investments laid the groundwork for the remarkable growth in clean energy in the United States that has occurred over the past seven years. Solar electricity generation has increased over 30-fold since 2008. Wind generation has increased over three-fold since 2008. Through a variety of mechanisms, ARRA funding reached nearly every aspect of the value chain for numerous key clean energy technologies, including advanced vehicles, batteries, carbon capture and sequestration, and technologies to enhance energy efficiency. These investments are a down payment towards an innovative 21st century clean economy and promise to yield benefits for many years into the future.

Some of the highlights of the ARRA funding include the Advanced Research Projects Agency-Energy program for early-stage innovations, several of which are already on their way to market; electric vehicle battery manufacturing facilities in many states; over 180 awards to advanced clean energy manufacturing; deployment of smart meters in states across the nation; and weatherizing more than 800,000 homes. There is an economic rationale for using funding designed to stimulate the economy to invest in projects of long-term value. The clean energy-related projects funded by ARRA help address a variety of market failures, including environmental and innovation market failures.

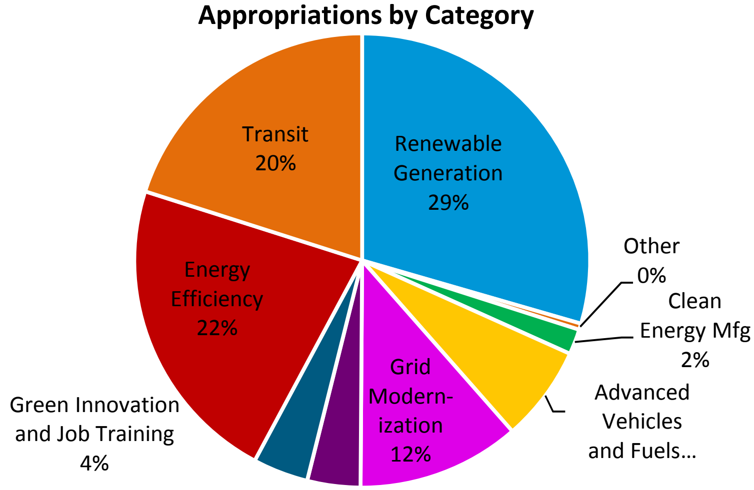
Since ARRA, there has been continual growth in clean energy jobs that has withstood significant headwinds. While there is more work to do to keep us on track to a sustainable 21st century economy, the clean energy ARRA investments were an important step in the right direction.

Highlights of the ARRA Clean Energy Related Investments

The bold investments in clean energy through ARRA had a substantial macroeconomic impact, supporting the U.S. economy at a critical moment by raising output and supporting jobs.

- Over $90 billion of ARRA funding was invested in clean energy and related technologies. These investments covered renewable energy generation, clean transportation, energy efficiency, grid modernization, advanced vehicles and fuels, carbon capture and storage, green innovation and job training, and clean energy manufacturing.

Figure 1: Distribution of Initial Clean Energy Appropriations by Category



Source: CEA (2010).

- The ARRA clean energy-related programs supported roughly 900,000 job-years (full-time jobs over one year), from 2009 to 2015. Many of these jobs provided employment during a significant labor market downturn. Previous CEA analysis estimated roughly 720,000 job-years were supported from 2009 to 2012.

- Clean energy investments made up over one eighth of total ARRA spending and provided a meaningful boost to economic output. CEA estimates that ARRA raised the level of GDP by between 2 and 3 percent from late 2009 through mid-2011.

ARRA's clean energy policies laid the foundation for a long-term transition to a cleaner economy by improving clean energy markets, unlocking private capital, helping drive down clean energy technology costs, and expanding research and development of new technologies.

- The ARRA funding not only provided a stimulus, but also helped address market failures in clean energy markets. The diverse set of funding mechanisms helped to address market failures such as environmental externalities, innovation market failures, and capital market failures by investing in measures across the clean energy value chain.

- Solar electricity generation has increased over 30 times from 2008 levels, and wind generation has increased over three times. The investments made through ARRA helped to catalyze dramatic trends in clean energy over the past seven years. Along with the lift in renewable energy generation is a commensurate notable decline in technology costs for these technologies, making them all the more competitive against fossil fuel generation.

- ARRA investments in the deployment of clean energy technologies also helped contribute to dramatic cost reductions for those same technologies as part of a virtuous cycle. For example, the overnight capital cost of utility-scale photovoltaic (PV) systems fell from $4.1/watt (W) in 2008 to $2.0/W in 2014—a decrease of 50 percent. Cost reductions for this and other technologies resulted from a number of factors—including economies of scale, technology learning, and new business practices—that were assisted by the widespread deployment made possible by ARRA.

- ARRA has supported over $27 billion in investment in clean energy generation and capacity. These funds were complemented by investments to modernize the grid such that these new energy sources could play a role in providing clean energy to households and firms.

- Substantial ARRA clean energy funding was invested in long-run research and development, helping to bring transformative new technologies to fruition. The benefits from this investment are beginning to pay off, with new transformative technologies such as a 1 MW (megawatt) silicon carbide transistor, engineered microbes that use hydrogen and carbon dioxide to make liquid transportation fuel, and major advances in lithium-ion batteries.

ARRA helped catalyze substantial shifts toward cleaner energy sources, raising energy efficiency, supporting jobs, and building the infrastructure needed for large-scale use of clean energy.

- ARRA support helped improve residential energy efficiency by weatherizing over 800,000 homes, leading to over one million homes being weatherized between 2009 and 2012 with federal support. The Weatherization Assistance Program scaled up quickly and reached low-income homes across the country.

- ARRA energy efficiency investments are projected to save over 400 million MMBtu (million British thermal units) of energy over the next four decades, or the equivalent of annual energy consumption for 10,000 homes. Oak Ridge National Laboratory (ONRL 2015c) estimates that all ARRA investments will save 400 million MMBtu of energy from 2009 to 2050. This is equivalent to the entire annual energy consumption of 10,000 homes, if the savings are distributed equally over the years.

- A major demonstration carbon capture and storage facility in the United States was made possible through ARRA funding. As of May 15, 2015, the Air Products and Chemicals hydrogen facility in Port Arthur, Texas had successfully captured its second millionth metric ton of carbon dioxide.

- ARRA helped to support the training of over 30,000 students for solar careers and other clean energy careers. Over 25 Energy Training Partnership grants provided support for electrical apprenticeship training, programs targeting unemployed dislocated workers, women, minorities and veterans, and community groups serving unemployed and dislocated workers.

- ARRA helped lay the groundwork for a transition to a cleaner and more energy efficient transportation system with over $18 billion initially allocated towards cleaner transportation. This investment supported public transit with purchase of 12,000 buses, vans, and rail vehicles and the construction or renovation of over 850 transit facilities. It also supported high-speed rail through $8 billion allocated to 49 projects, 98 percent of which are either complete or with construction underway.

- The Clean Energy Manufacturing ARRA funding, along with the more stable wind turbine market facilitated by ARRA support, helped support a dramatic increase in the share of domestically-produced wind turbines used in the United States from 25 percent in 2006-2007 to 72 percent in 2012. The 30 percent clean energy manufacturing tax credit was a widely oversubscribed success, with numerous innovative projects across the clean energy space.

- The Smart Grid Investment Program helped to support the installation of 16 million smart meters by 2016. Smart meter projects around the country can help consumers understand their energy use and pricing, helping to facilitate the transition to a more resilient electric grid infrastructure.

- ARRA funds provided a matching grant to enable the deployment of over 4,600 electric vehicle charging stations**.** ChargePoint received a $15 million grant to leverage private funds to install charging stations in states across the nation to help support the emerging electric vehicle market.

I. Introduction

The American Recovery and Reinvestment Act (ARRA), also known as the Recovery Act, was signed by President Obama on February 17, 2009, at a time when the U.S. economy was contracting at a rate not seen since the Great Depression. There was a severe financial crisis, and a steep decline in consumer and business confidence, household wealth, and access to credit. In the last quarter of 2008, employment was falling by more than 700,000 jobs per month and U.S. real gross domestic product (GDP) contracted at an 8.9 percent annualized rate. ARRA was part of a comprehensive and bold countercyclical fiscal policy response to the economic turmoil that gripped the United States and the world economy.

ARRA's immediate goal was stabilize the economy, preserving and restoring jobs, and assisting deeply suffering industries. In a context of weak aggregate demand, already aggressive use of monetary policy tools bringing interest rates to near-zero levels, highly constrained credit, and expectations of protracted contraction, there is a strong economic case for a significant fiscal stimulus to increase near-term economic output. As documented in numerous reports, ARRA is estimated to have increased output and employment substantially relative to a baseline without the fiscal stimulus. For example, the Council of Economic Advisers (CEA) estimates that the entire ARRA package increased GDP between 2 and 3 percent from late-2009 to mid-2011.[1]

ARRA also provided a major opportunity for laying the groundwork for sustainable long-run growth and well-being. Indeed, there is a reason why the word "Reinvestment" was included in the title of the Act. A second goal of ARRA was invest in the foundation for a robust and sustainable 21st century economy. A sizable fraction of the ARRA funds were invested in projects that improved long-run productivity, such as transportation infrastructure improvements, as well as investments in innovative technologies, including clean energy technologies and related innovations.

This report focuses on these investments in clean energy and a sustainable 21st century economy. ARRA appropriated $787 billion at the time of passage, and this was later revised to $831 billion over the 2009 to 2019 period.[2] Of the initial allocations, $90 billion was allocated towards investing in a cleaner, more sustainable energy future.[3] These investments can be seen as a "down-payment" on the transition to a sustainable 21st century economy, and each has an economic rationale based on addressing multiple market failures, such as environmental externalities and innovation market failures.

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[1] See CEA (2014) for estimates of the aggregate economic effects of the ARRA and the literature on the use of fiscal stimulus in a recession.

[2] Those figures, though, include $69 billion allocated to a routine set of patches for the Alternative Minimum Tax (AMT). This part of the Act, a continuation of a long-standing practice, is best thought of as ongoing fiscal policy, not as a temporary fiscal impulse designed specifically to counter the effects of an economic recession. Excluding the AMT patch, the Recovery Act provided a total fiscal impulse of $763 billion.

[3] As described below, certain programs were extended or had greater take-up than anticipated. As such the total allocation of ARRA related clean energy programs will be over $90 billion. CEA calculations indicate that just under $90 billion of ARRA clean energy-related funding had been spent by the end of 2015.

This retrospective review of the clean energy and related investments provides several insights. It highlights dramatic trends of increased activity and innovation in clean energy markets over the past seven years. For example, solar electricity generation increased over 30-fold, and wind generation increased over three-fold since 2008. It reviews the direct contributions of the Recovery Act for jobs and economic activity. The ARRA clean energy programs are estimated to have supported roughly 900,000 job-years, where a job-year is a full-time job for one year. It also connects the dots between investments made in the Recovery Act and major innovative activity, such as the 400 potentially transformative Advanced Research Projects Agency-Energy (ARPA-E) projects. While formally proving causality for any policy, including ARRA, is highly challenging and requires a reliable counterfactual, this review provides evidence that ARRA contributed to one of the greatest increases in clean energy activity in the history of the United States, and supported hundreds of thousands of jobs that were much-needed in the wake of the financial crisis.

This report is a follow-on from a series of quarterly reports by the CEA on the effects of the Recovery Act on overall economic activity and employment that ran through the fourth quarter of 2013. The report adds new data on the dramatic trends occurring in clean energy markets and provides insight into where the ARRA clean energy funding was spent and the ways in which it contributed to clean energy development. As such, the report provides an assessment of the role of ARRA in leading the transition of the energy economy in the United States and a more complete picture of the Act's longer-term impacts on the U.S. economy.

The remainder of this report begins with a discussion of the economic rationale for clean energy investment as part of the ARRA package. Next is an overview of the clean energy funding under ARRA, which is followed by the notable trends in clean energy during and following ARRA and then a brief discussion of some of the highlights of the impacts of the key clean energy-related components of ARRA. Finally the report concludes with a discussion of why the ARRA clean energy-related investments were successful. Appendix I provides much greater detail on the major categories of programs, including many more examples of program impacts. Appendix II provides an overview of CEA's calculation of the ARRA clean energy spending over time used for the jobs estimate.

II. Economic Rationale for Clean Energy-Related Investment

Economic theory provides useful guidance for the development of policies and programs in the clean energy space. In particular, there are an array of market failures that can lead to underinvestment in clean energy, energy efficiency, and research and development in these areas relative to the socially optimal levels of investment. These market failures will come up throughout the discussion in this report of the different clean energy-related investments made under ARRA.

The first category of market failure that afflicts markets for clean energy and energy efficiency consists of environmental externalities from the burning of fossil fuels. These environmental externalities include damages from greenhouse gas emissions and other local air pollutants. If these environmental externalities are internalized into the market price for energy services, the price of fossil fuel-based energy would increase and the relative financial attractiveness of clean energy would improve, resulting in more clean energy investment. Thus, without some intervention to internalize these negative externalities or otherwise address this market failure, the market will underprovide clean energy.

A second category of market failure is the result of the positive externality of knowledge spill-overs. These market failures, called innovation market failures, lead to an underinvestment in innovative activity on new technologies by private actors because some of the returns from investment spill-over to other firms, implying that the social rate of return on innovative activity is much higher than the private rate of return. Innovation market failures are particularly important for fledgling technologies that are just being developed, for foundational advances may be difficult to patent and are more likely to spill-over to other firms than incremental advances in mature technologies.

The most common example of an innovation market failure is the research and development (R&D) market failure from imperfect appropriability of innovations (i.e., those who innovate cannot appropriate or capture the returns from the innovation). R&D market failures lead to underinvestment in R&D activity. Another example of an innovation market failure is the market failure from cost declines due to learning-by-doing (i.e., improving processes and lowering costs with additional experience) in the technology that spill-over to other firms in a market. Learning-by-doing spill-overs would dampen the incentive to quickly ramp up production in a new technology to gain experience. Clean energy technologies are often susceptible to both R&D market failures and learning-by-doing market failures because they are new technologies with significant gains still to be made (and spill-over to others in society) from both research and learning.[4] Again, this implies that the private market left to its own devices will underprovide clean energy innovation investment.

[4] See Jaffe and Stavins (1994) or Gillingham and Sweeney (2012) for a more detailed discussion of innovation market failures in the context of clean energy.

A third market failure is the possibility of energy security externalities from the use of oil, which many clean energy technologies, particularly in the transportation sector, can help offset. As discussed in work by Brown and Huntington (2013) and Nordhaus (2009), when the U.S. economy is exposed to oil price shocks, there can have significant macroeconomic effects. These oil price shocks may occur from crises on the other side of the world, such as wars, revolutions, and decisions made by foreign countries. Thus oil is underpriced when one considers the cost to the economy from relying heavily on oil, leading to underinvestment in clean energy technologies that help reduce oil consumption.

A fourth category of market failures that may lead to underinvestment in clean energy and energy efficiency consists of information market failures. These may be due to inadequate or poor information about new clean energy or energy efficient consumer technologies. In the context of energy efficiency, these information market failures may even interact with behavioral failures, such as consumer myopia (i.e., consumers only focusing on the very short-run at the expense of the long-run for a particular good or service in a way that is different than other choices consumers make) leading to an overweighting of the upfront costs for energy-using durable goods relative to other decisions consumers make. There is some evidence that these issues could lead to underinvestment in consumer energy efficiency decisions.[5] It is also possible that they could influence clean energy purchases.

Other market failures may also affect clean energy investments in certain circumstances. During times with extremely tight credit markets, such as just after the 2008 financial crisis, there is often limited availability of capital for investments in promising new technologies. These capital constraints very likely afflicted clean energy investments just as the ARRA funding became available. Such capital constraints at times of crisis call for greater availability of financing for promising new technologies.

In some cases, there may also be network externalities that influence the adoption of new technologies that rely on network effects. Network effects imply that the value of a product is greater when there is a larger network of users of that product. For instance, electric vehicle charging stations are more valuable if there is a large network of charging stations and many electric vehicle drivers. The same is true for biofuel refueling stations. Sometimes these network effects are internalized already by the producer of the product. However, in the case of many clean energy technologies, either the benefits do not all accrue to the producer or the scale of investment required to create the network is so large (especially important during times of tight credit markets), that these network effects are not internalized, and thus there is an underinvestment in the clean energy technologies. Government support can not only provide the needed funds, but it can also act as a signal to the market that a particular technology has support, influencing expectations of future growth and investment decisions.

[5] E.g., see Gillingham and Palmer (2014) and Allcott and Greenstone (2012) for reviews of the academic literature on market and behavioral failures in energy efficiency policy.

Such a diverse array of market failures affecting clean energy markets provides an economic rationale for the use of a variety of policy tools for government intervention. It also underscores that when a sizable stimulus package is needed for macroeconomic purposes, there is an economic rationale for investing this funding in clean energy-related technologies that will provide long-term benefits. Not only did the ARRA funding alleviate macroeconomic concerns, but the investments help to address several important market failures. The package of clean energy-related investment in ARRA helps to spur clean energy markets all along the value chain, as will be seen in the following sections.

III. Overview of Clean Energy Funding Under the Recovery Act

The over $90 billion ARRA investment in clean energy-related sectors represents one of the largest investments in these sectors in U.S. history. For example, it was an order of magnitude larger than the five-year $6.3 billion Climate Technology Initiative proposed during the Clinton Administration. Further, the ARRA clean energy-related investments leveraged on the order of $150 billion in additional private and non-federal capital in investments toward advancing the deployment of energy efficiency, wind, solar, geothermal, biomass, low-carbon fossil fuel, and other technologies.[6]

Direct investments from ARRA funded a variety of different projects with long-run implications. These projects were broadly targeted to help address market failures, such as environmental externalities and innovation market failures. For example, grants for deployment of renewable energy projects, such as solar photovoltaic (PV) projects, helped to reduce greenhouse gas and other pollutant emissions. Similarly, these grants may have fostered learning-by-doing spill-overs through a growing and publicizing of the market. Many of the projects involved research and development at critical points in the value chain when the technology spill-overs to others are likely to be large, and thus the private investment especially low.

The ARRA clean energy-related investments can be divided into two categories based on the funding mechanism. First, there were 45 investment provisions with an initially estimated total allocation of $60.7 billion. These provisions were primarily focused on areas of high-value investment to prime a sustainable 21st century economy. Second, there were 11 tax incentives, which the U.S. Treasury estimated will invest $29.5 billion through fiscal year 2019.[7] These tax incentives were primarily focused on fostering new technologies in the renewable energy and advanced vehicle technology space, but also provide strong support for energy efficiency. Such investments accelerated the growth of key new technologies, which will help reduce environmental externalities and U.S. reliance on oil for years to come.

Another way to categorize the ARRA clean energy-related investments is by the broad category of project. Figure 1 illustrates the distribution of the initially allocated $90 billion investment across eight broad categories of clean energy projects: renewable generation, energy efficiency, grid modernization, advanced vehicles and fuels, transit, carbon capture and storage, green innovation and job training, clean energy manufacturing. Figure 2 illustrates the breakdown of initial allocations by spending category, and shows that 67 percent of the allocations went towards spending and 33 percent went towards tax credits.

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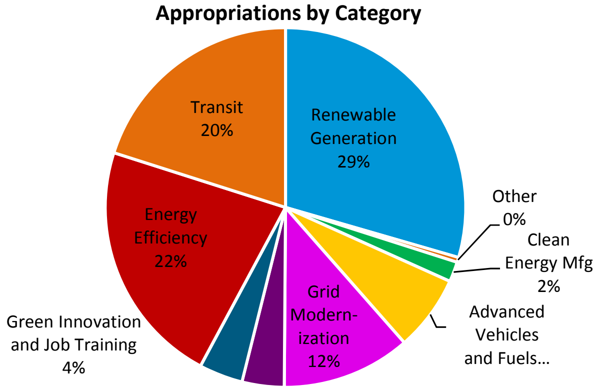
[6] CEA (2010) calculates that $46 billion of the $90 billion initial allocation has a co-investment component and that this $46 billion leverages over $150 billion in private and non-federal capital investment. See Aldy (2013) for a more detailed discussion of the co-investment component of the ARRA clean-energy investments.

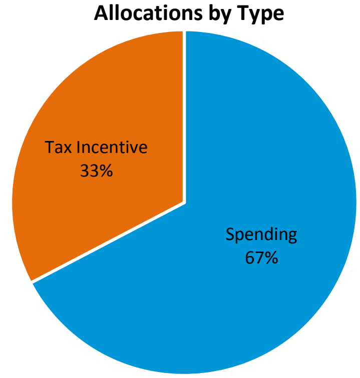
[7] This estimate only considered tax credits in place in 2010, and does not include investments from later extensions of the tax credits (CEA 2010).

Figure 1: Distribution of Initial Clean Energy Appropriations by Category



Source: CEA (2010).

Figure 2: Distribution of Initial Clean Energy Allocations by Type



Source: CEA Calculations.

At nearly 30 percent, the largest category of allocations consisted of investments in renewable energy generation, which both induced innovation and helped address environmental externalities. At 22 percent, the next-largest category of allocations went towards investments in energy efficiency, also reducing environmental externalities. Transit investments made up 20 percent of allocations, and served to build infrastructure to both improve economic productivity and reduce transportation emissions. At 12 percent of allocations, grid modernization also served to improve infrastructure, increase electricity system reliability, and demonstrate new technologies for a more resilient and sustainable electricity grid. The remaining investments in advanced vehicles and fuels, green innovation and job training, carbon capture and storage, and clean energy manufacturing all served to foster innovation in new technologies, preparing the United States for a longer-term shift to a clean 21st century economy.

A key element in all of the ARRA clean energy-related investments is that while they were designed to provide long-term benefits, the allocations focused as much as possible on projects that were "shovel-ready" and could be deployed relatively quickly, in order to take advantage of resources in the economy that were under-utilized due to the Great Recession. In short, the allocations aimed to put people back to work and contributed to both the recovery and reinvestment goals of the legislation. More broadly, the choice of allocation across the many possible projects was based primarily on a several criteria: the ability to deploy resources quickly, the potential for federal support to stimulate private financing, existence of administrative and authoritative capacity for policy implementation, CO_2 reduction potential, and impact per dollar in employment, economic activity, and changes to the energy system.[8] Federal capacity to administer programs and funds were also considered to help assess feasibility. All of these considerations led to a wide variety of funding mechanisms and policy approaches, as will be seen later in this report.

[8] Summers (2008) suggests that any package intended to provide stimulus should be, at least initially, driven by the "3-T's"; they should be "timely, targeted, and temporary." These principles echo the strong preference for shovel-ready projects and using existing programs to distribute the funds in as timely a manner as possible while the need is the greatest.

All ARRA spending was channeled through federal agencies before being disbursed to state and local governments or other recipients. Much of the energy-related funding; including for energy efficiency, carbon capture and storage, and grid modernization; was administered by the U.S. Department of Energy (DOE).[9] The U.S. Treasury Department handled much of the support for renewable energy through tax incentives and cash grant program; the Federal Transportation Administration (FTA) and Federal Railroad Administration (FRA) handled transportation funding.

Table 1 shows the breakdown of ARRA spending across the categories of clean energy-related investment. The second column shows the initial allocation of funding across categories based on the 2009 allocations. These sum up to the total of $90 billion, which is the standard number used to describe the ARRA clean energy investments. However, some of the programs were tax credit programs, rather than allocations of funding. For example, the 1603 Cash Grant program for renewables and the 30 percent clean energy manufacturing tax credit were both tax credit programs. Both of these programs were in high demand, and in fact the clean energy manufacturing tax credit was significantly oversubscribed. Other programs, such as tax credits for advanced vehicles, continue past 2015 and may not have spent all of the allocated funding by 2015. CEA estimates that the final allocation out to 2019 will add roughly $15 billion to the total sum, bringing it to roughly $105 billion. Of that total, CEA estimates roughly $88.5 billion has been spent so far. Non ARRA-related extensions of any of the programs, including the production tax credit and investment tax credit, are excluded from these totals.

Table 1: ARRA Clean Energy Initial Allocations

	Initial Allocation Assessment ($ Billions)
Renewable Generation	26.6
Energy Efficiency	19.9
Transit	18.1
Grid Modernization	10.5
Advanced Vehicles	6.1
Green Innovation & Job Training	3.5
Carbon Capture and Sequestration	3.4
Clean Energy Equipment Manufacturing	1.6
Other	0.4
Total	**90.2**

Source: CEA (2010)

Based on the ARRA spending, it is possible to estimate the impact on employment. Previous CEA analysis estimated that ARRA clean energy-related investments helped support roughly 720,000 job-years (where a job-year is one year of full-time equivalent employment) over the period from

[9] Carley and Hyman (2013).

2009 to 2012.[10] This was based on the extent to which initially allocated funding had been spent out over that period. Including further spending over the last three years, CEA estimates roughly 900,000 job-years were supported by the $88.5 billion ARRA clean energy-related investments from 2009 to 2015.[11] When all of the ARRA funds have been spent out by 2019, CEA analysis suggests that over one million job-years will have been supported from 2009 to 2019. Many programs have been continued long beyond the ARRA time frame and continue to provide both employment and long term benefits to the economy. Further, many programs also leveraged and made possible significant private investment, which supported additional jobs. This report focuses on the investments directly funded or originated under ARRA.

[10] These CEA estimates include both direct, indirect, and induced jobs. Direct jobs include people hired directly by the government or its grantees or contractors to do the work paid for by the stimulus. Indirect jobs are additional people hired by suppliers to and subcontractors of the original recipients to provide the inputs needed for the projects. Induced jobs are people who are hired because of the extra spending by workers hired in direct and indirect jobs. Roughly two-thirds of the job-years are direct and indirect clean energy jobs; the remainder are induced jobs.

[11] The estimate of 900,000 job-years is calculated based on a macroeconomic multiplier similar to previous CEA ARRA analysis adjusted for changes in nominal GDP and the labor force. Other approaches yield an even larger estimate; for example, using a full macroeconomic model yields an estimate of over one million. The estimate includes direct, indirect, and induced jobs, as defined in footnote 10.

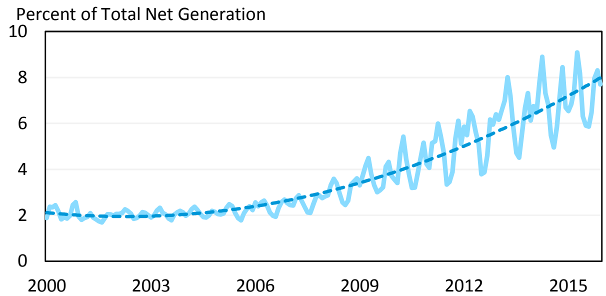
IV. Dramatic Trends in Clean Energy Markets

Clean energy in the United States has made enormous strides over the past seven years since 2009. Electricity generation from renewable energy sources has skyrocketed, and costs for technologies like wind turbines and solar panels have plummeted. The clean energy economy has also supported high quality jobs and robust employment growth. While the vast progress that has been made across the clean energy sector cannot be entirely attributed to ARRA, ARRA support has played a role in the dramatic trends that can be observed in clean energy markets.

Growth in Renewable Energy Generation

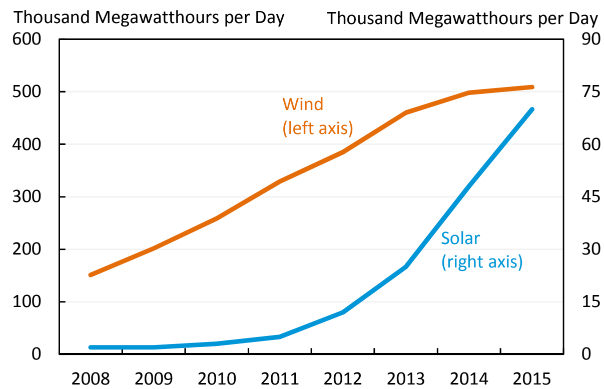
To begin, the share of electricity generated by non-hydro renewables has increased from roughly 2 percent in 2005 to over 8 percent in 2015 (Figure 3). Growth in wind-powered and solar-powered electricity generation has been particularly notable. Data from the Energy Information Administration (EIA) show that since 2008, electricity generation from wind has more than tripled, and electricity from solar has increased 30-fold (Figure 4).

Figure 3: Monthly Share of Non-Hydro Renewables in Net Electric Power Generation



Note: Dotted line is a smoothed trend, shown to dampen the strong seasonal patterns (the share of non-hydro renewables drops during the winter and summer-both seasons of high power generation demand).
Source: Energy Information Administration.

Figure 4: Electricity Generation from Wind and Solar



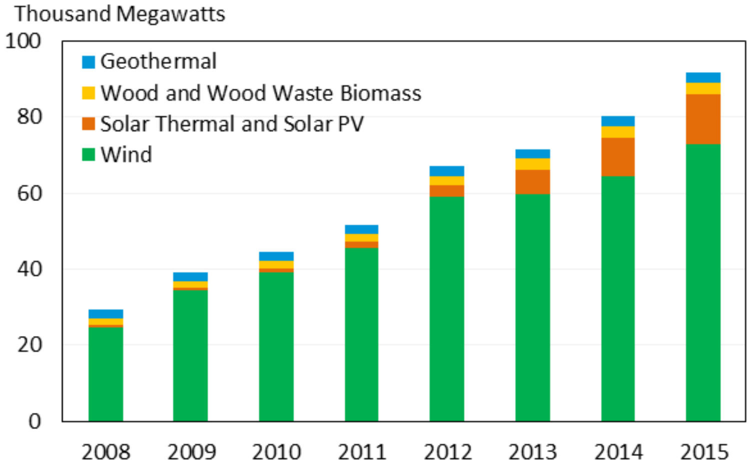
Source: Energy Information Administration.

Many factors have contributed to this dramatic growth. There have been improvements in both wind and solar PV technologies. Many states have implemented renewable portfolio standards. And many states and municipalities have other policies to encourage renewable energy generation. All of these other factors complement the major investments in wind and solar technology development and deployment in ARRA.

Growth in Renewable Energy Capacity

Along with the rapid growth in new electricity generation from renewable sources has been a commensurate surge in renewable energy capacity. Electric generation capacity refers to the maximum output that a generator can produce, while electricity generation refers to the actual electricity produced. As illustrated in Figure 5, non-hydro renewable energy capacity in the United States more than tripled between 2008 and 2015, from a total of less than 30 thousand megawatts to almost 100 thousand megawatts. Most of the increase was driven by growth in wind and solar capacity.

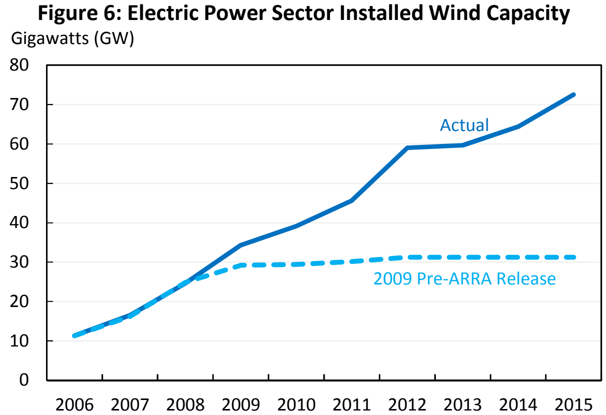
Figure 5: U.S. Non-Hydro Renewable Energy Electric Power Sector Installed Capacity



Source: Energy Information Administration.

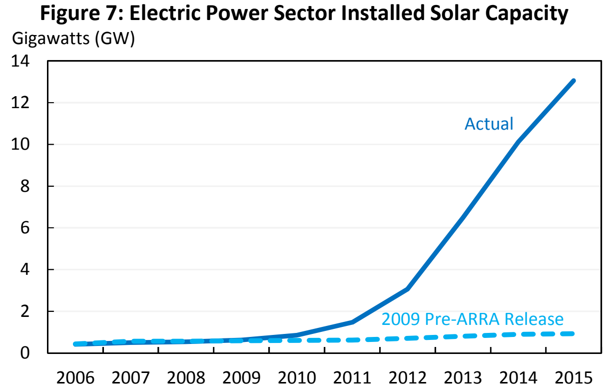
The growth in renewable energy capacity has not only been impressive, but it also far exceeded expectations prior to the enactment of ARRA. The dashed lines in Figures 6 and 7 show EIA's projections for installed wind and solar capacity made in an early release of the 2009 Annual Energy Outlook (AEO) that excluded any forecasted impacts from ARRA. The solid line in each figure shows actual installed capacity, which is well above the pre-ARRA projections.

Figure 6: Electric Power Sector Installed Wind Capacity



Source: Energy Information Administration.

Figure 7: Electric Power Sector Installed Solar Capacity



Note: Includes solar PV and solar thermal.
Source: Energy Information Administration.

Just as described above, the impressive performance of the clean energy sector since 2008 cannot be solely attributed directly to ARRA policies. Other factors very likely complemented the ARRA clean energy investments and also contributed to renewable capacity growth. That said, ARRA funds contributed significantly to investments in clean energy projects in several ways as will be further discussed below, and are a major contributor to the remarkable and unexpected growth in the market observed over the past several years.

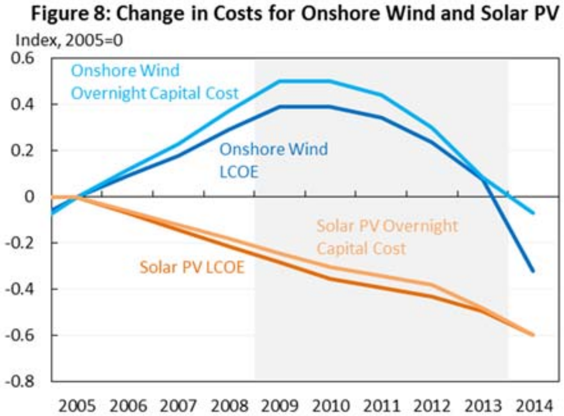
Lowered Clean Energy Costs

Along with the considerable growth in generation by renewables, there have been sizable declines in the cost of renewable and other clean energy technologies since the ARRA investments. For example, LED lighting has seen a nearly 90 percent decrease in cost per kilo lumen since 2008. Battery costs for electric vehicles have fallen from almost $1,000/kWh in 2008 to under $300/kWh in 2014.[12] But in particular, the costs of wind and solar PV technology have notably declined in recent years, and are rapidly becoming cost competitive with traditional fossil fuel sources.

A common metric for comparing cost competitiveness between renewable and conventional technologies is the "levelized cost of energy" (LCOE). The LCOE represents the per-kilowatt-hour cost (in real dollars) of building and operating a generating plant over an assumed financial life and duty cycle. Several key inputs are taken into account when calculating LCOE, including capital costs, fuel costs, fixed and variable operations and maintenance costs, financing costs, and an assumed utilization rate for each plant type.[13] Importantly, the availability of various incentives including state or federal tax credits are also factored in. Because solar and wind technologies have no fuel costs, their LCOEs are highly dependent on the estimated capital costs of generation capacity and available incentives, and can vary substantially by region.

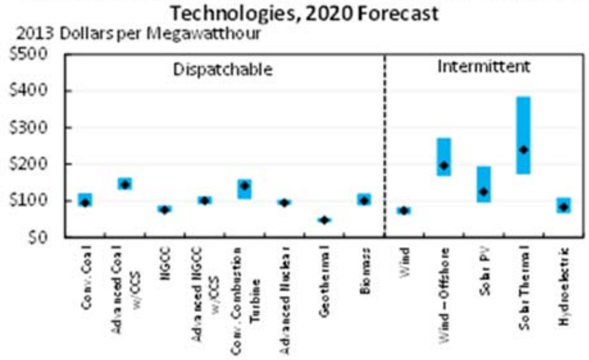
Based on both LCOE and overnight capital costs (the cost to build a power plant if no interest was incurred during construction), wind and solar costs have fallen substantially over the past decade. Figure 8 indicates the pattern of costs over time since 2005, with the shaded area indicating the time period in which the ARRA programs were in the greatest effect (note that several ARRA programs have continued past the end of 2013). As illustrated in Figure 9, the LCOE for onshore wind technologies was down 32 percent in 2014 from its 2005 level, and the cost of solar PV was down 60 percent. Overnight capital costs have also declined, by almost 10 percent for wind and 60 percent for solar.

Figure 8: Change in Costs for Onshore Wind and Solar PV



Source: NREL; Wiser, Bollinger et al. 2013; Lazard 2014.

Figure 9: Total System LCOE Comparison Across Generation Technologies, 2020 Forecast



Note: Shaded region reflects minimum and maximum of range.
Source: Energy Information Administration.

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[12] DOE (2015).
[13] EIA (2015).

The decline in the levelized cost of wind technology over the last decade has been somewhat slower than the declines seen for solar technology. In fact, average wind turbine prices actually more than doubled between 2002 and 2008 before resuming a downward trend. The increase in turbine prices during the pre-ARRA period was influenced by several factors, including higher prices for materials, energy, and labor inputs and an increase in turbine manufacturer profitability due in part to robust demand growth and turbine and component supply shortages. In addition, over the past 15 years there has been a substantial increase in turbine size, including hub height and rotor diameter. According to the U.S. Department of Energy, the average nameplate capacity of newly installed wind turbines in 2014 was up 172 percent since 1998-1999, and average hub heights and rotor diameters increased 48 and 108 percent, respectively, over the same time period.[14] So, while the levelized costs were declining modestly, the technology was also improving, allowing for wind installations at sites that were previously uneconomic and possibly implying even larger actual cost savings over the past decade than if the technology was held fixed.

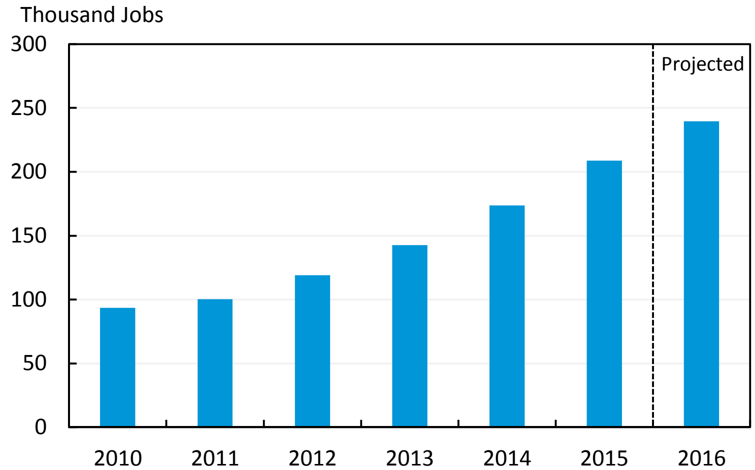
Currently, there is a wide range of costs for new wind and solar generation. There are already some places in the United States where new wind—without any subsidies or accounting for externalities—can compete head-to-head with new fossil fuel generation on purely a technology cost basis. Moreover, in many locations in the United States, the cost for new wind and solar is at or below the cost of new fossil fuel generation when including subsidies and tax credits used to promote renewable generation. Adjusting for environmental externalities would tip the balance even further. Without taking into account subsidies or externalities, however, wind and solar on average remain more expensive forms of new generation than coal or natural gas, underscoring the continued need for government support to catalyze greater investment in renewable generation. Promisingly, forecasts for wind and solar PV costs from the EIA and the International Energy Agency (IEA) suggest that the unsubsidized technology cost of new wind and solar without subsidies will be on par or below that of new coal by 2020 (Figure 9). The ARRA investments in wind and solar unquestionably played a role is helping these technologies get to scale and become more competitive.

Major Job Growth in the Renewable Energy Sector

Employment in the renewable sector spans several categories in Federal data collection systems, which complicates direct estimation of job growth and output in the sector. However, trade association data suggest that, along with the rapid expansion in wind and solar electricity generation, there has also been a sharp rise in employment. From 2010 to 2015, employment in the solar energy industry more than doubled, and is expected to increase by another 15 percent in 2016 (see Figure 10).

[14] EERE (2015).

Figure 10: Solar-Related Employment



Source: The Solar Foundation, National Solar Jobs Census 2015.

Between 2010 and 2015, the solar industry has added workers at a pace 12 times faster than the overall economy. In fact, solar jobs accounted for 1.2 percent of all net jobs added in the United States in 2015. Employment in the wind industry has also been quite robust. In 2012, when jobs were needed the most, employment reached 80,000. It since dropped some from this level, but increased again from 2013 to 2014, reaching a total wind industry employment of roughly 73,000 workers in 2014, up from 50,000 in the prior year.[15] These are high quality jobs too—Brookings (2011) reports that the median wage for a typical clean economy job approaches $44,000, which is above the national median wage.

[15] AWEA (2015).

V. Highlights of the ARRA Clean Energy Investments

Across the eight major categories of clean energy investments listed in Figure 1, ARRA funding laid the groundwork for the transition to a clean energy economy. This section provides a brief overview of some of the highlights from the ARRA clean energy-related investments. The review covers the categories in Figure 1, in order from largest to smallest in terms of funding allocation. Appendix I goes into much greater detail on each of the different categories of investment, including much more discussion of the program impacts.

Renewable Generation

As noted, clean energy investment may be underprovided by the market due to unpriced environmental externalities from fossil fuel use, innovation related market failures, and capital market constraints due to the challenges of a financial crisis. ARRA supported renewable energy generation by both expanding existing incentives and adding programs. The two primary programs that were expanded were the production tax credit (PTC) and investment tax credit (ITC). ARRA extended the production tax credit for renewable energy generation by three years, expanded eligibility for the 30 percent investment tax credit for renewable projects, and removed a cap on investment tax credits, which allowed for small wind projects.

Acknowledging the challenges that certain renewable developers had in taking advantage of the tax incentives available at the time, ARRA also created two new programs to support renewable energy generation. First, by providing loan guarantees for renewable energy projects, the 1705 Loan Guarantee Program addressed the difficulty of securing financing renewable projects in the then-prevailing market conditions. The 1705 program supported the construction of the first five solar PV projects over 100 MW in the United States for a total of 1,502 MW in renewable energy capacity.[16]

Further, ARRA created the 1603 Cash Grant program, providing renewable energy projects with a cash grant equal to 30 percent of project costs as an alternative to taking the investment tax credit. As tax equity markets tightened during the financial crisis, the 1603 Cash Grant program allowed for the development of renewable energy projects by entities that lacked sufficient tax liability to take advantage of other tax incentives. Through 2015, the 1603 Cash Grant has provided $25 billion in awards to support 9,915 businesses in a range in technology types, supporting a total installed capacity 33.3 GW, and an estimated annual electricity generation of 88,700 GWh.[17] For a typical household using 11,000 kWh per year, this would imply that the total electricity generation would power over 8 million homes per year.

[16] LPO (2015).
[17] UST (2016a).

Energy Efficiency

In addition to investing in a cleaner energy supply, the Recovery Act also helped reduce energy demand through a suite of investments designed to increase energy efficiency in homes, commercial buildings, and factories. All of these programs are designed to help address environmental externalities by reducing energy use, most of which is provided by fossil fuels. Those programs that reduced the use of fuel oil also could help reduce reliance on foreign oil production and thus may help reduce energy security externalities.

Oak Ridge National Laboratory (ORNL 2015c) projected that total ARRA energy efficiency investments will save over 400 million MMBtus of energy over the next four decades. Assuming the savings happen uniformly over that period, this is nearly 10 million MMBtu per year, or the equivalent of the annual energy consumption for 10,000 homes. In particular, the expansion of the Weatherization Assistance Program (WAP) with nearly $5 billion in additional funds supported the weatherization of over 800,000 sites over the 2009 to 2013 period, with an estimated 97 million MMBtu energy saved and over 5 million metric tons of carbon saved. [18] One of the most valuable features of allocating funding towards WAP was the ability to utilize existing administrative capacity and ramp up quickly. In fact, most of the ARRA WAP funds were spent by the end of 2013. This supported jobs at a time they were much-needed; WAP supported 28,000 direct and indirect jobs in 2010 alone.[19]

Clean and Energy Efficient Transportation

ARRA helped lay the groundwork for a transition to a cleaner and more energy efficient transportation system with over $18 billion initially allocated towards cleaner transportation. This investment supported public transit with purchase of 12,000 buses, vans, and rail vehicles and the construction or renovation of over 850 transit facilities. It also supported high-speed rail through $8 billion allocated to 49 projects, 98 percent of which are either complete or with construction underway. Further, the ARRA transportation investments enabled the deployment of over 4,600 electric vehicle charging stations around the country.

Clean Energy Manufacturing

ARRA supported clean energy manufacturing through investment tax credits for a wide range of clean energy products such as equipment for renewable energy generating facilities, energy storage, energy conservation, carbon capture and sequestration, fuel cells, and the refining and blending of renewable fuels. The credit was awarded for 30 percent of project costs to clean energy manufacturers on a competitive bases. Interest in the program greatly exceeded initial expectations, with over 500 applications seeking $8 billion in credits. Since this was much above the allocated funding level, funding was increased, allowing for awards in the amount of $2.3 billion to 183 domestic clean energy manufacturers, promoting the development of a domestic supply chain to support a growing clean energy industry.

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[18] Energy savings calculation based on site estimates from ORNL, further described in Appendix I.

[19] ORNL (2015a).

Other Initiatives

Initiatives under the other five categories of spending also made important contributions to help lay the groundwork for a long-term shift toward a clean energy economy. The Smart Grid Investment Program helped to support the installation of 16 million smart meters by 2016, and a major demonstration carbon capture and storage facility in the United States was made possible through ARRA funding. Finally, substantial ARRA clean energy funding was invested in long-run research and development—an investment that will continue to pay off far into the future by helping to bring about major advances in transformative technologies.

VI. Conclusions

The American Recovery and Reinvestment Act represented an unprecedented clean energy investment in United States history. The investment had a dual purpose: jump-starting the economy to get Americans back to work and at the same time making a long-run investment or down payment towards the transition to a sustainable 21st century economy. Thus, it was designed to leverage existing administrative and technical capacities so that the investments could get off the ground quickly. This meant building on existing tax credits, providing funding on a competitive basis to grantees with experience, leveraging private capital, and expanding currently existing successful programs in addition to creating new ones. These clean energy investments through ARRA provided a strong economic boost, and by the end of 2015 have supported roughly 900,000 job-years.

While most of these investments occurred quickly—roughly 70 percent of the initial allocation was spent by mid-2013, providing a boost at the time it was most needed—the investments can be expected to provide benefits long into the future. Moreover, there is a strong economic case for the investments based on helping to address market failures. Nearly all of the investments will help address environmental externalities either in the short or long run. But many also help address innovation market failures that slow the innovation so critical to long-run economic growth. Still others help address further market failures, such as energy security externalities, information market failures, and severe capital constraints that occurred as a result of the financial crisis. Just as there are multiple market failures, the ARRA investments involved multiple policy mechanisms. Further, such a mix of policy mechanisms focusing on multiple technologies and multiple innovation opportunities not only addresses barriers all along the innovation value chain, but also enables the best technologies to succeed.

While many of the investments are in early-stage technologies that may take time to pay dividends to society, there are already remarkable trends in clean energy markets. The concentrated focus on encouraging clean energy innovation and deployment sent a strong and consistent signal to markets, contributing to the greatest growth in renewable electricity generation in history. This growth occurred alongside, and helped facilitate, dramatically decreasing costs for clean energy technologies. In fact, there are many places in the United States where renewables are less expensive than traditional fossil fuel generation on a levelized cost basis. These dramatic trends in renewable energy markets were not projected prior to ARRA.

The long-term investments made under ARRA supported jobs at a critical time, helped address market failures, and are setting the stage for the transition to a clean energy-based, sustainable 21st century economy.

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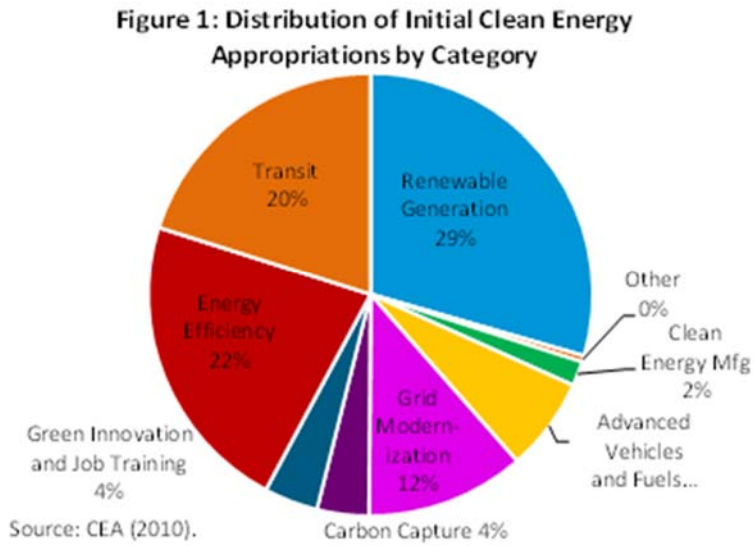
Appendix I: Details of the ARRA Clean Energy-Related Investments

This report has illustrated the major shifts in renewable energy markets during and after the major ARRA clean energy-related investments. This appendix takes a closer look at these investments, by drawing upon the best evidence available on the impact of the funding. The discussion will cover each of the major categories of programs illustrated in Figure 1 (shown again here for convenience), proceeding in order of the size of the allocation to the category. The discussion demonstrates the great diversity of funding approaches and mechanisms, ranging from loan guarantees and competitive merit-based cost-shared grants to support for leadership and capacity building.



Renewable Energy Investments

The Recovery Act supported renewable energy generation working through several programs. Two of the major programs were the production tax credit (PTC) and investment tax credit (ITC), both of which were expanded or extended by ARRA. In addition, ARRA included two new programs, the 1603 Cash Grant program and the 1705 Loan Guarantee Program.[20] Finally, ARRA also provided support for renewable energy through increased funding for bonds for renewable energy, called Clean Renewable Energy Bonds (CREBs).

Combined, these programs supported the dramatic increase in renewable energy generation observed over the past decade, and likely also contributed substantially towards spurring technological innovation. For example, over the past seven years, wind installations have seen large increases in hub heights and larger rotors, which allows for viable wind project development in new regions where previously the wind resources could not be successfully

[20] The 1705 program modified the pre-existing 1703 program to include conventional renewable energy projects, transmission projects, and biofuels projects.

accessed. While it is impossible to attribute technological innovation to any single cause, Mundaca and Richter (2015) examine clean energy patents over the period 2009 to 2012 and provide evidence suggesting that clean energy innovation was substantially encouraged by the ARRA programs.

Production Tax Credit and Investment Tax Credit

Prior to ARRA, federal support the renewable energy project investment and development occurred primarily through the PTC, most often used by wind developers, and the ITC, most often used for solar energy developers. Both types of policies can help address environmental market failures by encouraging renewable energy development that offsets fossil fuel generation. At the same time, they also provide incentives for private investment in innovation in these technologies by raising the expected rate of return on these technologies. They were exceptionally useful as part of the ARRA because they were already well-established and thus could quickly be put to work to achieve rapid stimulus effects.

Prior to the Recovery Act, production tax credits offered performance-based incentives for eligible renewable energy generation technologies (excluding solar) through rebates of $0.023/kWh for wind, geothermal, and closed-loop biomass and $0.012/kWh for other eligible technologies (in 2015 dollars). ITCs supported project investment by offering tax credits of 30 percent of project costs for solar, fuel cells, and small wind and 10 percent for geothermal, micro-turbines, and CHP renewable energy projects.

The Recovery Act expanded the impact of these credits through several mechanisms. First, it extended the expiration date of the PTC. Specifically, ARRA extended the PTC for wind facilities to December 31, 2012 and for other technologies to December 31, 2013 (the ITC was already given an 8-year extension in 2008, so the key contribution of ARRA on the solar market was the 1603 Cash Grant program). This extension was critically important because previously there was an annual boom and bust cycle in wind and other renewables development due to uncertainty about whether these credits would be renewed.[21] Subsequent extensions following ARRA have allowed ITC/PTCs to continue to support renewable energy project investment and generation through 2016 and beyond.[22]

Second, ARRA increased ITC support for small wind projects by removing a previously imposed cap of a $4,000 maximum amount of credits claimed for wind less than 100kW in capacity. Third, it allowed facilities eligible for the PTC to elect to claim the ITC instead. This provided additional optionality for large wind projects previously only eligible for a PTC.

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[21] Mundaca and Richter (2015).

[22] Most recently, PTC/ITCs were again extended in December 2015. ITCs are available for solar technologies excluding hybrid solar lighting through 2019 at 30 percent, ratcheting down to 10 percent by 2022. ITCs for large wind are available at 30 percent through 2016, phasing out by 2020; ITCs for geothermal continue at 10 percent; ITCs for other eligible technologies through 2016. PTCs for wind were extended through 2016 with a phase down over 2017 - 2019; for other eligible technologies PTCs expire after 2016.

1603 Cash Grant Program

The 1603 program offered cash grants to renewable energy project investments for an amount of up to 30 percent of a project's capital costs.[23] Project developers had a choice between taking this cash grant or one of the tax credits, such as the investment tax credit. Eligible projects for the cash grant were required to commence construction by December 31, 2011, or incur 5 percent of project costs by the end of 2011.[24] While the investment tax credit was also available for up to 30 percent of a project's capital costs, there were several advantages to providing a cash grant.

The first is that some renewable energy developers may not have had a sufficient tax liability to claim the tax credits. Many renewable energy developers are small companies, with a limited tax burden. In order to take the ITC, such companies would have to enter into a financial agreement with a partner that would provide tax equity in return for the claimed tax credits. During normal economic times, this may be a relatively easy transaction, but during the financial crisis, it became difficult to find such partners. [25]

A second advantage is that even if it may have been possible to find a partner, in a time of financial turmoil there is an increased risk that the partner would back out. With certainty of the grant funding, renewable energy project developers found it easier to raise project debt. Aldy (2013) also points out that financiers were hesitant to support long-term investment projects when there was uncertainty regarding the future of the PTC and ITC. The 1603 Cash Grant program provided the cash grants quickly, thus reducing uncertainty.

A preliminary analysis of 1603's impact by LBNL (2010) finds additional benefits to developers from the cash grant program rather than a tax credit program. These benefits accrue from reducing the dependence on scarce or costly third-party tax equity to monetize a project's federal tax benefits. Financing is less expensive using project-level term debt and carrying depreciation deductions forward in time until they can be absorbed by the project (i.e., "self-sheltering"). The report estimates the value of self-sheltering at around 8 percent of installed project costs for wind developers. LBNL also estimates that the 'face value' of the cash grant is higher than after-tax economic value of the ITC/PTC, estimated around 2.2 percent of installed project costs for wind power projects.[26]

LBNL (2010) further examines early 1603 recipients and does not find any evidence of inefficient project design, which would lead to poor performance. Inefficient project design could be a concern for a cash grant program because by its structure, it does not specifically incentivize

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[23] UST (2016a).

[24] When the 1603 program was first established, the project construction start date required was December 31, 2010. In 2010 this deadline was extended to December 31, 2011. 1603 projects with a construction start date in 2011 are also included in the CEA calculations for in this report.

[25] NREL reports the number of tax equity investors willing to make investments decreased from 20 to around 5 during 2008-2009.

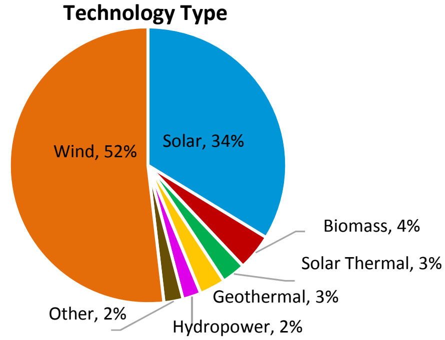
[26] LBNL (2010).

efficient project construction. However, nearly all renewable energy projects sell electricity through a power purchase agreement (PPA), which involves safeguards to attempt to ensure efficient project construction.

The Treasury Department reports that $25 billion in funds were used to support the development of renewable energy facilities through the 1603 Cash Grant program as of January 1, 2016.[27] Including private, regional, and state, and federal investments, $90 billion has been invested in 1603 projects.[28] Funds have supported 9,915 businesses to develop projects of the technology mix below, showing that the dominant firm technology type was for solar electricity, making up 80 percent of the firm awards associated with 76,000 solar projects.[29] The next largest firm technology, wind, comprised 9 percent of awarded firms; solar thermal constitutes 5 percent of awarded firms, and the remaining 10 percent come from a variety of other sources.[30]

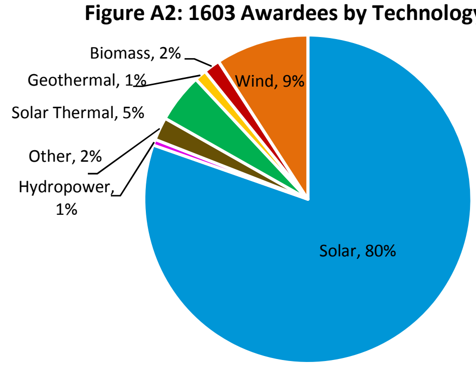
Figure A1 and A2 show that while solar firms dominate the count of awardees, wind projects received more of the funding in aggregate. The average award for a wind project is much larger than the average award for a solar project.

Figure A1: Distribution of 1603 Awarded Funding by Technology Type



Note: "Other" includes the Fuel Cells, Landfill Gas, Marine, Microturbine, Combined Heat and Power, and Trash Facility.
Source: U.S. Treasury Department.

Figure A2: 1603 Awardees by Technology Type



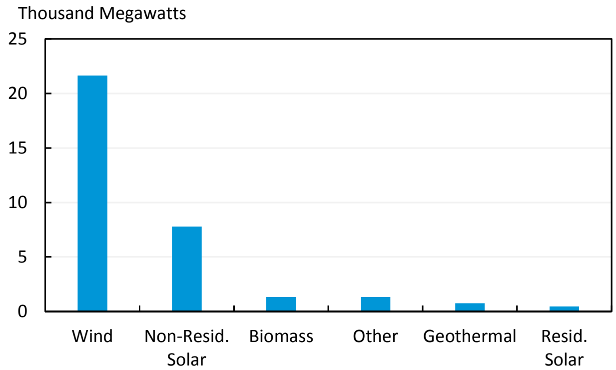
Note: "Other" includes the Fuel Cells, Landfill Gas, Marine, Microturbine, Combined Heat and Power, and Trash Facility.
Source: U.S. Treasury Department.

Figure A3 illustrates the generation capacity and estimated generation from 1603 Cash Grant-funded projects through 2015. Wind and non-residential solar PV are the largest categories: 1603 grants funded projects that generated 56,200 GWh from wind and 14,300 GWh from non-residential solar PV as of December 31, 2015. By the end of 2015, the program funded a total installed capacity 33.3 GW, translating to an estimated annual electricity generation of 88,700 GWh. Figure A4 below shows the estimated generation from supported projects by project type.

[27] UST (2016b).
[28] UST (2016a).
[29] Mundaca and Richter (2015).
[30] The Treasury Department's status update shows 104,211 projects as of December 31, 2015; the awards spreadsheet keeps track of funding by firm name and not project. All the graphs below are based on number of firms, and not number of projects.

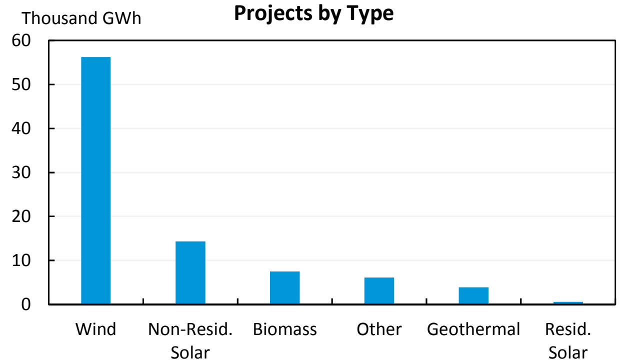
The cost of supporting this renewable generation was $0.23/kWh for wind and $0.59/kWh for non-residential solar PV (in 2015 dollars).[31]

Figure A3: Generation Capacity from 1603 Projects by Type



Note: Figure represents capacity as of December 31, 2015.
Source: Department of the Treasury.

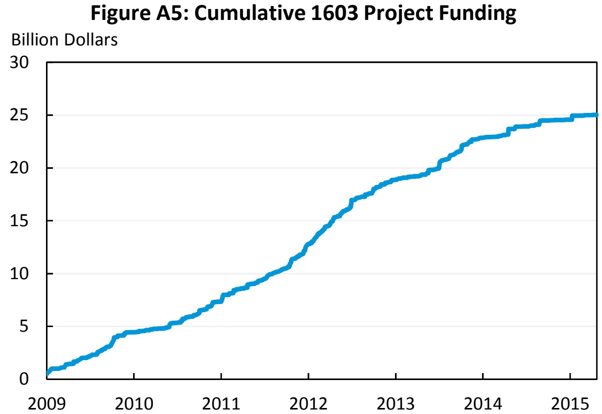
Figure A4: Estimated Generation from 1603 Projects by Type



Note: Estimates as of December 31, 2015.
Source: Department of the Treasury.

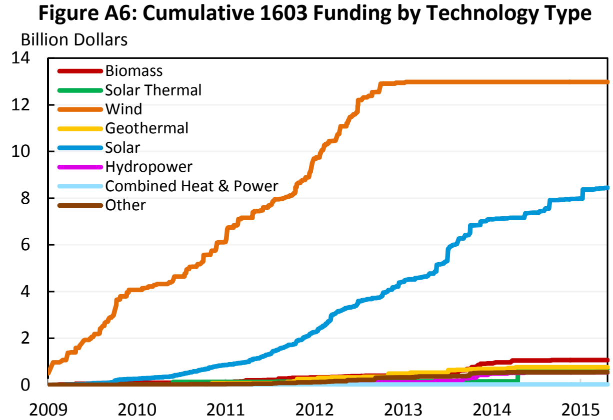
Figure A5 and Figure A6 below illustrate the timing and destination of the 1603 project funding. As wind was the most competitive technology, the majority of the project funds went towards wind energy, followed by solar PV, with nearly all of the solar PV coming from non-residential solar PV.

Figure A5: Cumulative 1603 Project Funding



Source: U.S. Treasury Department.

Figure A6: Cumulative 1603 Funding by Technology Type



Source: U.S. Treasury Department.

NREL (2012) estimates gross jobs as a result of the 1603 program and finds that through November 10, 2011, the solar PV and large wind projects that received 1603 funds supported an average of 52,000 to 75,000 direct and indirect jobs over the 2009 to 2011 period from construction and installation-related expenditures. These estimates reflect the impact of $9 billion in 1603 funds supporting 13.5 GW in electric generating capacity, which is over one percent of the 2011 total summer generating capacity. Further, the report finds the 1603 projects led to up to a $26 to $44 billion increase in total economic output over the period analyzed. Taking these estimates for the period 2009 to 2011 at face value, and scaling the estimates to

[31] This calculation divides total federal project funding for the respective technology per the Treasury Award List by total energy for projects per the Treasury 1603 Status update (UST 2016a).

the current total of generation capacity supported by the program (33.3 GW), suggests at least a doubling of these employment and economic output estimates.

1705 Loan Guarantee Program

The 1705 program provided loan guarantees for renewable energy generating facilities that began construction prior to September 30, 2011.[32] While a previously existing loan guarantee program (1703) offered loans for innovative commercial energy programs, 1705 modified the 1703 program to include conventional renewable energy sources, transmission, and biofuel projects. An expanded eligibility of loan guarantees supported renewable energy project finance during the time of the financial crisis, when there were severe credit constraints. The loan guarantees turned out to be particularly useful for large utility-scale solar PV projects, which were having great difficulty obtaining financing due to severe credit constraints from the financial crisis. As of year-end 2015, an estimated $1.47 billion in ARRA funds have been directed toward the 1705 Loan Guarantee Program.[33]

Over $4.6 billion in loan guarantees from the 1705 program supported the construction of the first five solar electricity generation projects over 100 MW in the United States. These five projects, financed between 2010 and 2012, led to a total of 1502 MW of solar electricity capacity either operating or under construction. The 1705 program also supported Brookfield Renewable's Granite Reliable Wind Farm, a 99 MW wind power generation project located in New Hampshire, with a $169 million partial loan guarantee. The project was one of the first onshore wind projects to use a 3 MW turbine for its electrical generation technology, leading to cost reductions on a per megawatt basis.

In addition, the 1705 program has supported five concentrating solar power projects with a total generation capacity of 1,252 MW and an expected 3,544 GWh of annual generation. One such project includes Crescent Dunes, a 110 MW facility that concentrates solar energy to heat molten salt and upon completion will be the large molten salt power tower in the world, projected to mitigate 279,000 metric tons of CO_2 annually. The 1705 program also supported NextEra Energy's Genesis project with a partial loan guarantee through the Financial Institution Partnership Program (FIPP) to support a 250 MW facility using parabolic trough technology preventing 322,000 metric tons of annual CO_2 emissions.[34]

No investment portfolio is perfect, but the Recovery Act's clean energy programs have had some pretty remarkable results. The standard rule of thumb in venture capital is that three out of four start-ups fail. The DOE Loan Programs Office has provided $34.2 billion in loans and loan guarantees, and companies have defaulted on only $780 million--a loss rate of only approximately 2 percent. DOE also has collected $810 million in interest payments, putting the program $30 million in the black.

[32] LPO (2015).
[33] DOE (2016a).
[34] DOE (2016b).

Clean Renewable Energy Bonds

Clean Renewable Energy Bonds (CREBS) provide another financing mechanism for renewable energy projects. State and local governments, cooperative electric companies, clean renewable energy bond lenders, and Indian tribal governments can issue these bonds, which are a type of tax credit bond. Rather than the issuer paying interest, the federal government pays the interest in the form of tax credits, so the issuing entity can borrow at lower effective interest rates, and sometimes even as low as zero interest rates.[35] Thus, CREBS supports investment in renewable energy by lowering the cost of debt.

CREBS were first established by the Energy Policy Act of 2005 and received additional funding through the Tax Relief and Health Care Act of 2006. The Energy Improvement and Extension Act of 2008 further allocated $800 million in funds for CREBS, accompanied by new rules and requirements for CREBS as compared to the program prior to 2008 ("New CREBs"). ARRA increased the funding available for New CREBS by $1.6 billion, for a total New CREB allocation of $2.4 billion.

In October of 2009 the U.S. Treasury Department announced $2.2 billion in allocation of new CREBs to public power providers, cooperative electric companies, and government bodies supporting 805 projects across the nation. Of these allocations, public providers received $800 million, electric cooperatives received $609 million, and government bodies including cities and school districts received the remaining $800 million. The remaining unallocated $190 million in funds were distributed through a solicitation in September 2010 explicitly for electric cooperatives such that CREB volumes across the three entity types would equitable. Bonds are intended to be used within 3 years of notice of allocation, and any unused bonds after this time frame are relinquished and may be offered in future solicitations.

In 2009, CREBs allocations supported 22 renewable energy projects from municipalities, 31 from electric cooperatives, and 736 from governments for 711 solar, 47 wind, 15 biomass, 26 hydropower, and 3 geothermal renewable projects. Governments made greater use of CREBs, but for smaller projects. Just as much funding was allocated to municipal utilities as governments, but municipal utilities only were awarded 22 larger projects, far fewer than the 736 government projects.

San Diego County in California provides one example of successful application of the CREBS program to support public sector development of renewable energy projects. A non-profit in San Diego led a collaborative effort engaging university and high school students to develop a financial model for CREBs, focusing on on-site solar projects and application for smaller allocations of $1 million or less. $154 million in CREBS funding was allocated for 192 projects

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[35] The New CREBs included program changes that reduced annual tax credit rate allowed by 70 percent. If a risk profile of a given project led the market to require a higher rate than this reduced rate, the issuer of the bond would likely compensate the investor with supplemental interest payments. An additional program change removed the requirement that the issuer make equal annual payments over the term; in the new program the issuer has the flexibility to repay the full principal at the maturity date (NREL 2009).

across municipalities, school districts, universities, and a water district in the region, supporting 20 MW in new solar power.

Investments in Energy Efficiency

Over $27 billion funds have been spent on a host of projects and grant programs to improve building energy efficiency, for research and demonstration of energy efficient technologies, and for support for development of forward-looking state energy plans.[36] The larger programs included the Weatherization Assistance Program (WAP), State Energy Programs (SEP), Energy Efficiency & Conservation Block Grant Program (EECBGP), and Residential Energy and Energy Efficiency Property Tax Credit. Other smaller programs supported energy efficiency technology research and demonstration, smart appliances, green investments in assisted living, public housing, and federal buildings.

All of these programs are designed to help address environmental externalities by reducing inefficient use of energy, which also reduces energy generation-related emissions. Those programs that reduced the use of fuel oil also could help reduce reliance on foreign oil production and thus may help reduce energy security externalities. At the same time, some of these programs have a specific emphasis on low-income households and thus have the additional aim of keeping the most vulnerable Americans warm and healthy. WAP is among the most notable in this category.

Weatherization Assistance Program

WAP started in 1976 and since then has provided grants to states for energy efficiency improvements to low-income families. Specifically, funds for WAP are distributed to the states as a function of the climate in the state and the average energy bills of low-income households. States then distribute the funds to sub-grantees, typically community action groups or other non-profit entities that identify eligible households. Eligible participating households receive a free energy audits and home retrofits that can include insulation, window replacement, furnace replacement, and air infiltration reduction.

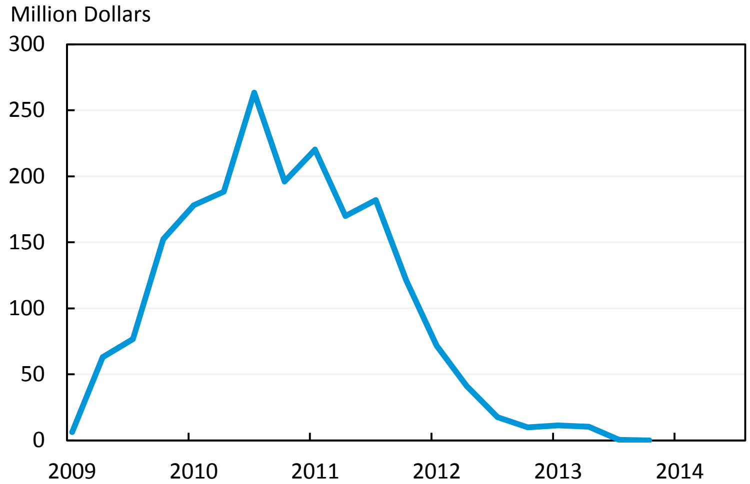
While WAP had been providing energy efficiency improvements prior to the Act, ARRA dramatically increased WAP funding from $230 million per program year to roughly $5 billion over three years.[37] One reason for this dramatic ramp-up in funding is that WAP was relatively easier to scale up than some other programs, due to the existing administrative capacity and industry experience with the program. The broad goals for this increase in funding to WAP were: 1) job creation at a time when it was much needed, 2) energy conservation and security, and 3) relief for household burdened with high energy costs.

[36] This amount exceed the 2010 estimate of $19.9 billion directed toward energy efficiency. The difference stems from higher outlays for residential energy efficiency credits than forecasted in 2010.

[37] Along with the funding increase, the WAP income eligibility requirement was adjusted upwards to within 200 percent of the poverty line from 150 percent, and the average weatherization cost per site was increased from $2,500 to $6,500.

The WAP program was able to spend money rapidly and increase economic activity during the years of the greatest labor market slack. The DOE's record of Recovery Act funding shows $4.9 billion spent by May 2013. Figure A7 shows the distribution of ARRA WAP expenditures tracked by the DOE PAGE database over time, underscoring how this funding not only was an investment in the future, but also was very well-targeted to provide stimulus and jobs in the wake of the financial crisis.[38]

Figure A7: ARRA WAP Expenditures

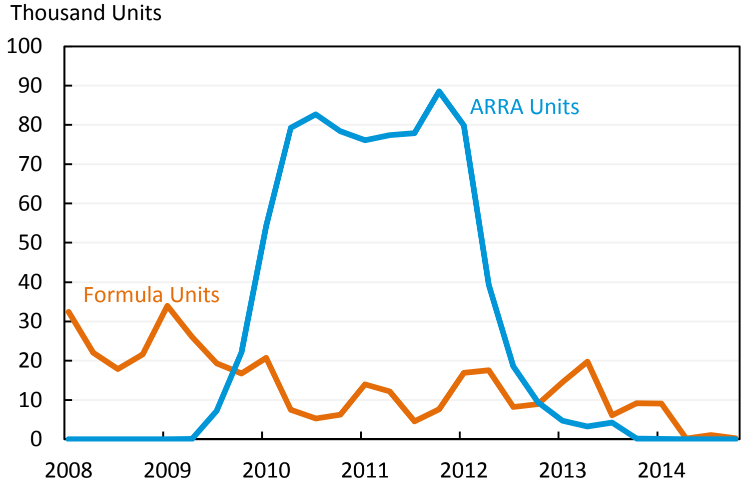


Source: Department of Energy, PAGE Database.

Figure A8 shows the number of ARRA units and non-ARRA units (i.e., formula units funded through the standard process) weatherized from Q1 2008 to Q1 2014. The spending seen in the previous figure led directly to hundreds of thousands of weatherized units from Q3 2009 to Q3 2012, exactly the time when a stimulus was most needed. In fact, when combining the ARRA funds and the formula funds, over one million units were weatherized between April 2009 and September 2012.

[38] The WAP expenditures in the DOE PAGE database do not sum up to the total ARRA expenditures for WAP as the database only tracks a subset of total program spending. However, nearly all ARRA WAP spending was before mid-2013, just as in the DOE PAGE database.

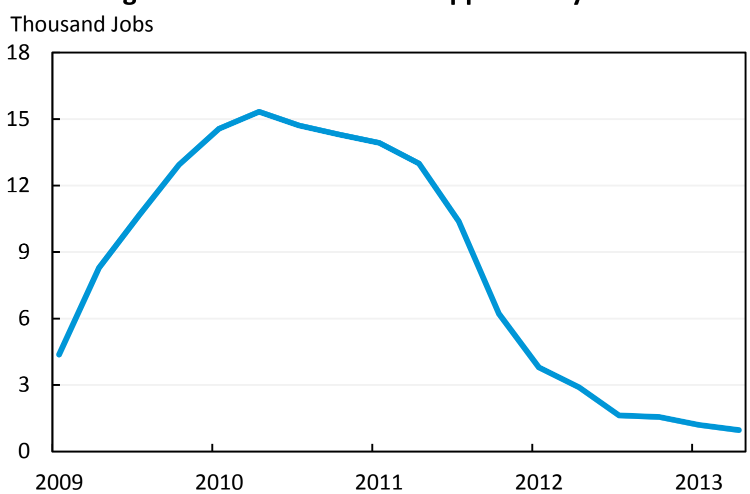
Figure A8: ARRA Weatherized Units



Source: Oak Ridge National Laboratory.

Oak Ridge National Laboratory (2015a) uses a general equilibrium model to estimates the jobs impact of the rapid expansion of WAP that was supported by ARRA. For example, they estimate that about 28,000 jobs were supported in program year 2010 due to the ARRA WAP funds. Figure A9 plots the recorded number of jobs per quarter supported by the site weatherization that occurred in that quarter. The jobs depicted reflect direct employment per quarter, and do not include indirect impact on jobs through expenditures on each site on energy efficient technologies.

Figure A9: Estimated Jobs Supported by WAP



Source: Oak Ridge National Laboratory.

ORNL estimates that for Program Year 2010 (PY 2010), weatherized sites observe an average savings from heating and electricity used as recorded by utility bills of 26.6 MMBtu in first year for site-built homes, 16.4 MMBtu for mobile homes, and 15.9 MMBtu for large family homes.[39] These estimates are within the range of those in other studies. For example, Fowlie et al. (2015) estimates a savings of 17.2 MMBtu per weatherized unit in Michigan and a previous ORNL evaluation of WAP Program Year 1989 finds a savings of 17.6 MMBtu per year.[40]

For Program Year 2010, 65 percent of homes were site-built, 15 percent were mobile family, and 20 percent were large multi-family. Applying the above estimates of savings per unit to the over 800,000 sites ORNL notes are weatherized with ARRA funds over the 2010 to 2013 period implies that there would be an estimated 97 million MMBtu saved as a result of the ARRA funds in the WAP.[41] Taking the average of the ORNL savings estimates across site types gives an average savings of 19.63 MMBtu per site per year. Using the EIA (2009b) summary data on household energy consumption and expenditures to estimate average expenditures per MMBtu, the energy savings from WAP lead to an average savings of $444 per year per weatherized site.[42]

ORNL calculates equivalent emissions reductions from PY 2010 energy savings using state-specific emissions factors based on state-specific energy portfolios. With this approach they estimate a reduction of 7,382,000 metric tons of carbon. If attributing the MMBtu to a reduction in an energy source with an emissions rate of natural gas, then this energy savings corresponds to a reduction in CO_2 by 403,482 for newly weatherized sites in PY 2010. Applying these estimates to all weatherized sites over the period 2010 to 2015 implies a reduction of over 5 million metric tons of carbon. This calculation is likely an underestimate to the extent that energy savings offset energy use from more carbon-intensive sources (e.g., electricity use from coal-fired generation).

State Energy Program (SEP)

The State Energy Program is managed by the DOE's Weatherization and Intergovernmental Programs Office (WIPO) and was created by Congress in 1996 by merging the State Energy Conservation Program (SECP) and the Institutional Conservation Program (ICP). The purpose of SEP is to support states' development of strategic energy plans by providing leadership and technical assistance. Such assistance often includes outreach activities, technology deployment, and access to new partnerships and resources. This assistance may help address information market failures and assist states in addressing environmental externalities.

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[39] Energy savings are calculated by collected monthly utility bills from natural gas and/or electric utilities for the 12 months pre and post-weatherization. Heating sources vary including natural gas and electricity; energy savings reflect combined heat and electricity savings.

[40] Fowlie at al. 2015; ORNL 1994. Note Fowlie et al. show that WAP has a similar effectiveness in saving energy, but differ substantially from ORNL in estimating a lower cost-effectiveness and benefit-cost ratio for WAP. The most significant differences relate to whether certain categories of benefits are included in the calculation.

[41] This calculation estimates total savings from 2010 to 2015. For example, for a site weatherized in 2010, this estimate includes 6 years of energy savings and assumes that energy savings in first year persist to future years. It also assumes a mix of single family, mobile unit, and multi-family unit in 2010 persists in future years.

[42] EIA (2009b) reports $2,024 average energy expenditures per household, with average usage per year of 89.6 MMBtu per household, for an average of $23/MMBtu. This estimate is used to map MMBtu savings from WAP to household savings.

For the Program Year 2008 prior to ARRA, SEP funding was $33 million. ARRA increased SEP funding to $3.1 billion over the period 2009 to 2011, with nearly all spent by May 2013. One third of SEP funds were allocated equally across states and territories, one third based on population, and one third based on energy consumption.

SEP support to develop strategic energy plans included building codes and standards, building retrofits, loans/grants/incentives for energy efficiency and renewable projects across an array of sectors, and the development of renewable energy capacity. Funding is also available to support preparations for emergencies and natural disasters. SEP encourages sustainable energy technologies across a broad host of sectors of the economy from the energy industry to schools and hospitals.

ORNL performed an evaluation of SEP for Program Year 2009. The evaluation separates the impact of the SEP into four key categories: building retrofits; building codes and standards; loans, grants, and incentives; and renewable energy market development. Because of the multitude of program types covered under SEP, the ORNL methodology involved an assessment based on a random sample of program types from funding recipients. This approach is inherently approximate, but it does acknowledge different ARRA program coverage rates across different activities. Table A1 presents the ORNL (2015b) assessments of lifetime of savings due to the 2009 SEP-funded projects. The results highlight significant energy savings, especially by residential and public institutional projects. They also highlight the substantial industrial sector renewable energy generation supported by SEP.

Table A1: Cumulative SEP-Attributable Energy Savings and Renewable Generation by Sector, 2009-2050

	Energy Savings (Trillion Btu)	Renewable Energy Generation (Trillion Btu)
Residential	289	3
Commercial	83	2
Industrial	40	2,069
Public Institutional	220	5
Private Institutional	56	1*
Total	**688**	**2,080**

Note: "*" indicates estimate exhibits low precision.
Source: Oak Ridge National Laboratory.

Energy Efficiency & Conservation Block Grant Program (EECBGP)

This grant program was developed as a one-time program to jump-start local investments in energy efficiency and conservation. ARRA appropriated $2.8 billion for individual program formula grants to states, U.S. territories, Indian tribes, counties, and cities to support the development, implementation, and management of energy efficiency programs, almost the entirety of which had been spent by the end of 2015.[43] Another $400 million was allocated for distribution through competitive grants. The grants were awarded for projects that reduced fossil emissions, reduced energy use, improved energy efficiency in transportation, building and other

[43] DOE (2016a).

sectors, and created or retained jobs. Given the limited duration of this grant program and the single funding cycle, projects with near-term execution timelines received funding preference.

Through the program, $2.6 billion in grants were allocated to 2,187 cities, counties, states, territories, and Indian tribes across 14 different grant categories. The largest category by funding is energy efficiency retrofits (38.8 percent of funding), followed by financial incentive programs (17.9 percent), and buildings and facilities (9.7 percent).

An ORNL (2015b) assessment of the program estimates that 409 million MMBtu will be reduced over the 2009 to 2050 period as a result of all of the combined programs included in EECBG. Assuming the savings happen uniformly over that period, this is nearly 10 million MMBtu per year. Based on the average natural gas usage per household reported by the EIA, these savings would be more than the entire annual energy consumption of 10,000 homes. Table A2 shows the ORNL estimated lifetime energy savings from the program by category of grant. Financial incentives are estimated to provide the largest energy savings, at nearly 58 percent of the total energy savings, since they leverage private funds to a much greater degree than the other grant categories.

Table A2: Estimated Lifetime Energy Savings Attributable to EECBG (2009-2050)

	Estimated Total Energy Savings (Trillion Btu)	Energy Savings as Percent of Total Savings in All BPAs
Energy Efficiency Retrofits	71	17.3%
Financial Incentives	236	57.6%
Buildings and Facilities	30	7.3%
Lighting	71	17.2%
On-Site Renewable Tech.	0	0.0%
Energy Efficiency and Conservation Strategy	2	0.5%
Total	**409**	**100.0%**

Souce: Oak Ridge National Laboratory.

There is also evidence from the academic literature that is relevant to understanding the effects of the block grant program, as well as the SEP. For example, 110 of the block grants are for the development of building codes. There is evidence that building codes are effective in saving energy. Jacobsen and Kotchen (2013) study the impact of building codes and estimate that building codes in Gainesville, FL led to 4 percent decrease in electricity consumption and 6 percent decrease in natural gas consumption. These estimated savings are close to the ex-ante predictions of the regulation's impact. In updated analysis in Gainesville using 11 years of billing data, Kotchen (2015) finds that while electricity consumption reductions from the building codes do not persist, reductions in natural gas consumption are persistent in the long-term.[44]

[44] Levinson (2014) finds that building codes in California do not have impacts on electricity consumption when controlling for building characteristics such as size, location, vintage, and characteristics of the residence. However, in contrast to Levinson (2014), Kotchen (2015) continues to find persistent energy savings.

Residential Clean Energy and Energy Efficiency Tax Credits

Over $10 billion has gone towards ARRA residential tax credits to encourage homeowner investments in renewable and efficient energy technology and property. These residential tax credits built upon previous tax credits for energy efficient investments already in existence at the time. ARRA removed or raised some of the previously imposed maximum credit amounts, allowing for a tax credit equal to 30 percent of the cost of a qualified investment.[45]

The expansion of these credits through ARRA contributed to the increase in the value of the credits by over three times over the 2006 to 2010 period. This larger credit value was accompanied by an increase in the number of claims over the period, with average annual claims in 2009 and 2010 increasing to over three times the number of claims in 2008.

With the support of these credits, homeowners have invested in insulation, energy efficient exterior windows, and energy efficient heating and air conditioning systems. The use of Energy Star criteria to establish eligibility of certain products helped to streamline rebate claims for qualifying improvements. Tax rebates were also provided for the residential purchase of renewable energy such as geothermal pumps, solar heating, solar electricity, fuel cells, and wind turbines. Over the period 2009 to 2010, over 13 million residential energy credits were claimed, with an average credit amount of $863 to $868.[46]

Transit Investments

As discussed in section II, clean energy programs can help address market failures in the clean energy generation, such as the existence of unpriced negative externalities from the combustion of fossil fuels. Cleaner transportation is another way to reduce the emissions from fossil fuel use. The failure to internalize the externalities may also bias transportation systems away from mass transit and other cleaner transportation options. Accordingly, ARRA allocations included funding for investments in rail and transit. By laying the groundwork for a shift towards a cleaner transportation system, these investments can help reduce environmental externalities, as well as other market failures, such as congestion and accident externalities.

High Speed Rail and Intercity Rail Capital Grants

ARRA provided close to $8 billion in funds to states across the country to develop a nationwide high-speed intercity passenger rail service. The funds have supported planning and construction projects to develop large-scale high-speed rail corridors across the country, targeted through investments in five key regions. The program received an additional $2 billion in 2011 for a total of $10 billion to support high-speed rail.[47] In addition to providing a more energy-efficient means of travel, the rail investment is intended to create and save jobs in track-laying, manufacturing,

[45] For Section 1121 rebates, ARRA raised maximum limit to $1,500, and for Section 1122 rebates, ARRA removed some of the previous caps. A credit of 30 percent of project costs up to $1,500 is permitted for energy-efficient installations were available for 2009 and 2010; the credit rate is 10 percent for installations in 2011 to 2016 with $500 maximum. Credits for renewable energy investments remained at 30 percent.

[46] CRS (2016).

[47] FRA (2016a).

planning and engineering, and rail maintenance and operation. To ensure that this investment leads to domestic jobs, both domestic and foreign rail companies have agreed to establish or expand their base to the United States if selected to supply the rail lines.

The Federal Railroad Administration (FRA) reports that to date, \$5.3 billion has been mobilized towards 49 construction projects that are underway or completed (24 completed) in 25 states and the District of Columbia. Additionally, one construction project of approximately \$3.4 million is expected to be underway by mid-2016. Approximately 98 percent of obligated construction projects have been completed or are currently underway. With a long-term vision of connecting 80 percent of Americans to high-speed rail in 25 years, ARRA funds aimed to balance long-term objectives of developing the infrastructure needed for a modern, low-carbon transportation system, while providing timely near-term job creation and demand for domestic manufacturing supply.

Projects supported by these funds include a \$4 million grant to develop a new transit center in San Francisco, with construction currently underway and expected completion in 2017. Funds were also awarded to support California's high speed trail system with initial construction underway and project completion in 2029. ARRA grants allowed for the development of 30 miles of new track for the expansion of the Amtrak Downeaster service to Freeport and Brunswick, ME, through a \$38 million grant providing service to these cities starting in November 2012. A \$15 million grant supported new tracks for freight train access without disrupting passenger service in the Port of Vancouver in Washington, completed in March 2015.[48]

Formula Transit Grants

The Federal Transit Administration has awarded \$8.78 billion through 1,072 grants to support transit capital assistance in urban, rural, and tribal areas as well as for investments in greenhouse gas and energy reduction, where \$6 billion of which was directed toward transit capital assistance in urban areas. In September 2010 the FTA reported having awarded all of its ARRA funding, with 16.4 percent of funds not yet disbursed.

ARRA funding has also provided over 12,000 buses, vans, and rail vehicles, and the construction or renovation of more than 850 transit facilities, and over \$620 million in preventative maintenance.[49]

Grid Modernization Investments

Transitioning to a clean energy electric portfolio involves sourcing electricity from increasing amounts of intermittent generating sources. Key renewable resources such as wind and solar require integrating intermittent resource profiles onto the electric grid. In this context, both on-going maintenance and modernization of U.S. electric grids with cutting-edge technology becomes important for keeping up with a changing electricity portfolio. For example, modern electric grids with advanced metering infrastructure (AMI), such as smart meters, pave the way

[48] FRA (2016b).
[49] FTA (2010).

for end-users to participate in the managing of an increasingly low carbon system. Consumers' thermal loads can be leveraged as energy storage opportunities through demand response and demand-side management programs, the deployment of which is greatly facilitated, and in some cases necessitates, AMI.

Investments in electricity delivery and reliability are core investments in economic productivity. Reliable electricity is essential for economic growth and a flexible resilient electricity system is an enabler that will allow for higher levels of penetration of renewable energy on the grid, thus helping to reduce environmental externalities.

The Recovery Act allocated $10.4 billion toward programs and projects to enhance the reliability of the nation's electric grid, to transform the grid in preparation of increasing intermittent energy supply, and for research and development of advanced grid technologies. $4.487 billion of these funds were appropriated to support states development of modern and reliable electric and energy systems. By the end of 2015, $4.4 billion of these funds had been outlaid.[50] A breakdown of spending is below in Table A3. As can be seen, most of the funding went towards investments in smart grids, which is discussed in more detail below.

Table A3: Spending for Grid Modernization

Program	Spending by End-2015 (Billion $)
Smart Grid Investment Grant Program (EISA 1306)	3.46
Smart Grid Regional and Energy Storage Demonstration Project (EISA 1304)	0.63
Workforce Development	0.09
Interconnection Transmission Planning and Analysis	0.08
Enhancing State and Local Governments Energy Assurance	0.05
State Assistance on Electricity Policies	0.04
Program Direction - OE	0.03
Interoperability Standards and Framework (EISA 1305)	0.01
Total	**4.39**

Source: U.S. Department of Energy

Smart Grid Investment Grant Program (SGIG)

Through the Smart Grid Investment Grant Program (SGIG, EISA 1306) DOE and the electricity industry jointly invested $8 billion in 112 cost-shared projects. Over 200 participating electric utilities and other organizations were involved. These projects focused on strengthening cybersecurity, improving interoperability, and collecting data on smart grid operations and benefits. Since 2009, $3.5 billion has been awarded and spent through the smart grid program as of year-end 2015.

Through the Smart Grid Investment Grant program, 11 synchrophasor projects (i.e., projects to provide real-time measurement of important metrics on the electric grid) have been completed,

[50] DOE (2016a).

installing over 800 networked phase measurement units (PMUs). PMUs improve electric grid reliability by allowing grid operators to identify and correct grid disturbances before they become major grid stability issues. In addition, the 65 SGIG smart meter projects reached the goal of installing 15.5 million smart meters, with over 16 million now installed and operational.[51]

An example of SGIG at work is the Florida Power and Light Company's (FPL) $800 million dollar project to modernize its electricity grid system, $200 million of which were supported by ARRA funds. With SGIG funding, FPL was able to expand its plan for smart grid projects by including over 5,000 intelligent monitors, sensors, and controls on the transmission and distribution system. SGIG funds also supported FPLs enhanced diagnostic system to collect and interpret data from substation devices and transmit information to FPL diagnostic centers for problem detection and outage prevention. For example, FPLs new Transmission Performance and Diagnostic Center (TPDC) remotely monitors 500 FPL substations to monitor voltage levels and impedance, allowing for substation problems to be detected and repaired before leading to outages. Further, the new smart grid capabilities provide customers with access to detailed information about usage and costs through an online "Energy Dashboard" displaying daily energy metrics.[52]

Smart Grid Regional and Energy Storage Demonstration Project

The Smart Grid Regional and Energy Storage Demonstration Project (EISA 1304) also supported modernization of the electric grid. It directed $684 million, along with a $900 million industry cost share, towards 32 Regional Smart Grid Demonstration and Energy Storage Demonstration projects under the Smart Grid Demonstration Program (SGDP).[53] One example of a successful EISA 1304 grant included a $45 million award to Consolidated Edison Company of New York, Inc., to demonstrate a scalable Smart Grid prototype that promotes cyber-security, distributed resources, electric vehicle charging and consumer participation in energy mix.

Investments in Advanced Vehicles and Fuels

The transportation sector is the second largest contributor of greenhouse gases in the nation, comprising 27 percent of national emissions in 2013, and its emissions have increased by 16 percent since 1990.[54] The combustion of petroleum-based products from passenger vehicles and light-duty trucks makes up over half of the emissions from the transportation sector. Developing new technologies is critical for reducing emissions from transportation.

The ARRA investments in advanced vehicles and fuels help to address environmental externalities, energy security externalities, innovation market failures, and even network externalities. The investments can help address environmental externalities in the long-run through a decarbonizing of the vehicle fleet. They can help address energy security externalities by replacing petroleum products with other fuels in transportation. They can help innovation

[51] EDER (2012).
[52] EDER (2012).
[53] Of the $684 million appropriated, almost all has been spent as of year-end 2015 (DOE 2016).
[54] EPA (2015).

market failures in both the short-run and long-run by fostering innovation with high degrees of spill-overs and high social returns. They can help address network externalities since there are network effects from sufficient refueling or recharging infrastructure. For instance, with few recharging stations for dedicated electric vehicles (EVs), each recharging station would have little value for few consumers would buy electric vehicles. But with many recharging stations, there is more likely to be an active market for electric vehicles, and thus each station has higher social value.

ARRA directed $6.1 billion toward programs to promote research on and deployment of the next generation of automobile batteries, advanced biofuels, plug-in hybrids, and all-electric vehicles, and the infrastructure needed to support operationalizing these technologies. Programs included funding for a tax credit for plug-in hybrid electric vehicles and dedicated electric vehicles of up to $7,500 per vehicle, with $2.2 billion allocated.[55] The tax credit for each qualifying vehicle model phases out after the manufacturer sells 200,000 qualified vehicles of that model. In addition, $2.4 billion in grants were awarded, along with cost-sharing, through a competitive process. These competitive grants support domestic manufacturing and deployment of advanced batteries and electric and plug-in hybrid vehicle components. $600 million of the ARRA funding was directed towards advancing biofuels. Further, $300 million of the ARRA funding was directed towards each of the following: alternative fueled vehicles pilot grant program, diesel retrofits, and federal motor vehicle fleet procurement.

Advanced Vehicle Tax Incentives

A growing body of economic literature demonstrates that tax incentives, such as the incentives in ARRA, increase the adoption rates and market shares of advanced vehicles. Most of this work has focused on hybrid vehicles, due to the lack of data on plug-in hybrid electric vehicles and electric vehicles. As a first example of how tax incentives increase the adoption of advanced vehicles, Gallagher and Muehlegger (2011) study the effect of government incentives on hybrid electric vehicle adoption from 2000 to 2006. They find that both sales tax waivers and income tax credits increase hybrid sales. Diamond (2009) also finds that government financial incentives increase the market share of hybrids, although gasoline prices have the strongest impact. Beresteanu and Li (2011) find a 20 percent increase in hybrid vehicle sales due to federal incentives using data from 2006. Sallee (2011) examines data on consumer purchases of the Toyota Prius hybrid vehicle and finds that the tax incentives are largely captured by consumers, rather than producers.

While these results in the economics literature may not entirely apply to plug-in hybrid electric vehicles or electric vehicles, they are indicative of the effects that may be expected from the ARRA tax incentives as well. Indeed, with the support of the tax incentive, sales of plug-in electric drive vehicles eligible for the credit reached nearly 69,000 from 2012 to the end of 2015.[56]

[55] Only $202 million of this estimated total allocation is forecasted to have been spent by the end of 2015 based on OST FY2012 forecast.
[56] IRS (2016).

Investments in Battery Technology and Transportation Electrification

The cost, size, durability, and safety of battery technology remains a critical hurdle to the widespread deployment of plug-in hybrid electric vehicles (PHEVs) and dedicated electric vehicles (EVs). The limited driving range and cost of most commercial EVs create a barrier to consumer adoption, and are largely due to the state of development of current battery technologies. The higher energy and power densities of lithium-ion batteries are essential for the feasibility of the current PHEVs and EVs, but there is still a great need for further improvement in battery technology.

Developments in improved battery technology have a very high social return, with batteries being used in a wide variety of commercial and military applications. ARRA investments in battery technology help address innovation market failures in battery technology development, encouraging the development of technology that will have spillover benefits across the economy. ARRA funds provided grant funding to support both the use and development in lithium-ion battery technology and the establishment of a domestic battery manufacturing supply chain.

The battery supply chain includes extracting raw materials, developing battery cell components, fabricating battery cells, and assembly of the battery pack. ARRA funds have supported companies all along the supply chain. Specifically, the Recovery Act supported the development of the lithium battery supply chain through grants of $28.4 million to develop lithium supplies, $260 million to produce cell components, $730 million for cells with different chemistries, $460 million for pack assembly facilities, and $9.5 million for a lithium recycling facility.[57]

One example of a grant awarded to support development of domestic electric vehicle supply chain was the $95.5 million to Saft America, Inc., for the production of lithium-ion cells, modules, and battery packs for industrial and agricultural vehicles and defense application markets. Another example is the $161 million grant awarded to Dow Kokam, now XALT energy, for manganese cathodes and lithium battery production at its plant in Holland, Michigan. Another went to General Motors for $105.9 million to produce lithium-ion cells and packs for the Volt.

The transportation electrification grant program also directed $400 million in grants for projects to advance the development of electric drive vehicle systems and infrastructure. For example, ChargePoint received a $15 million matching grant through the program for the deployment of over 4,600 home, public, and commercial electric charging points at an average cost of $3,300 of federal funds per charging station. Completed in 2013, the project also provides data to Idaho National Laboratory to provide researchers and planners the information needed to better understand charging patterns and future EDV infrastructure needs.[58]

In addition, ARRA funding supported "The EV Project" with a $115 million matching grant,[59] deploying 5,700 Nissan Leafs, 2,600 PHEV Chevrolet Volts, and 14,000 EV chargers and 300 DC

[57] CRS (2013).
[58] ChargePoint (2013).
[59] Matching funding lead to $230 million project budget (Schey et al. 2012).

chargers. Through a unique partnership across Nissan North America, General Motors, the Idaho National Laboratory, city, local and state governments and utilities, the EV Project implemented a large-sale electric vehicle charging infrastructure demonstration. The demonstration deployed EVs and chargers to collect data characterizing charging station usage across different localities, evaluate effectiveness of charging infrastructure, and analyze charging impacts on the electric grid. Such demonstration projects provide valuable data to researchers seeking to understand charging patterns and grid impacts, paving the way for improved and informed design of public and private charging networks.

ARRA also supported domestic manufacturing in batteries and energy storage though Section 48C grants for Clean Energy Manufacturing, as discussed below.

Investments in Carbon Capture and Storage

The transitioning to a low carbon energy system will likely require a diverse set of low-carbon technologies. Carbon capture and storage (CCS) technology offers the opportunity to reduce carbon dioxide emissions of existing power plants and industrial facilities, rapidly increasing the speed of decarbonization. CCS works by capturing carbon dioxide emission from large point-sources of emissions, transporting gases to subsurface rock formation, and permanently storing the carbon to prevent its release into this atmosphere. Equipping a power plant with CCS technology can reduce carbon emissions by 80 to 90 percent. In fact, the IPCC (2005) estimates that there is a technical potential of at least 2,000 Gt CO_2 storage capacity worldwide in geological formations, and predicts CCS will contribute 15 to 55 percent of worldwide mitigation effort through 2100.

ARRA authorized $3.4 billion in activities in CCS research and design, commercial demonstration, implementation, and education. While CCS technologies are successfully being deployed in this country and around the world, the development of any new technology is a difficult endeavor. Of the initial allocation, the DOE is returning $1.3 billion to the U.S. Department of Treasury for four CCS projects that were funded by DOE under the ARRA and were not able to advance to the point that the ARRA funding could be spent within the timeframe specified by statute. DOE's return of these ARRA funds to Treasury is a reflection of the significant challenges faced by businesses that are introducing innovative, early-stage energy technologies to markets and not necessarily a negative reflection on the readiness of CCS technologies.[60]

One successful project supported through ARRA funds includes the Air Products and Chemicals Inc. (APCI) hydrogen facility in Port Arthur, Texas. A $280 million ARRA grant to supports a $430 million dollar project combining CCS technology with enhanced oil recovery (EOR) to use the captured carbon to extract un-tapped fossil resources before it is stored underground. At full scale operation, the project captures over 90 percent of the carbon dioxide from the product steam of two methane steam reformers, translating to approximately 1 million metric tons of carbon dioxide delivered to sequestrations per year. On May 15, 2015, the DOE and APCI

[60] DOE (2016) estimates CCS spending through 2015 year end at $1.84 billion.

announced that the project had successfully captured its second millionth metric ton of carbon dioxide.

Green Innovation and Job Training

Green innovation and creating jobs in the sustainable 21st century economy are two of the key elements of the Recovery Act. Many of the areas described above involve research and development of new technologies. The green innovation and job training category completes the suite of clean energy research, again helping to address innovation market failures. The job training also allows our workforce to shift to be competitive in the 21st century economy.

The Recovery Act directed $3.5 billion towards programs to support research and development of advanced biofuels, clean energy-related information and communications technology, and enhanced geothermal systems. In addition, $400 million of these funds was allocated to the Advanced Research Projects Agency - Energy (ARPA-E) program, which funds new, creative research ideas aimed at accelerating the pace of innovation in advanced energy technologies. While the ARPA-E was created by statute in 2007, ARPA-E's first projects were funded by the Recovery Act. Funding in ARPA-E was focused on early stage innovations with very high social value.

ARPA-E has sponsored over 400 energy technology projects at the cutting edge of clean energy market transformation since its initial funding in 2009. Some examples include a 1 MW silicon carbide transistor, engineered microbes that use hydrogen and carbon dioxide to make liquid transportation fuel, and a near-isothermal compressed air energy storage system.[61] Other grant awards support a range of demonstration projects including a solar conversion tower to provide dispatchable solar energy, developing plants that produce vegetable oils in leaves and stems, algae harvesting from biofuels, and various projects working toward improvement in batteries and electricity storage.

The Recovery Act also included $500 million for competitive grants to state agencies and non-profits to support programs that train workers for jobs in the energy efficiency and clean energy industries of the future. It included another $100 million for training and hiring workers in the utility and electrical manufacturing sectors.

This ARRA funding for green jobs supported 25 Energy Training Partnership green job training grants to provide training for workers in energy efficiency and renewable energy industries. The grants support partnerships among labor organizations and public and private employers to design and distribute training methods, as well as build an understanding of green industries. Specific grants included support for electrical apprenticeship training, programs targeting unemployed dislocated workers, women, minorities and veterans, and community groups serving unemployed and dislocated workers. An example is the Solar Instructor Training Network (SITN), which was originally funded under ARRA, and has provided instructor training to more

[61] DOE (2016c).

than 1,000 qualified and credentialed solar PV instructors—leading to over 30,000 students throughout the United States receiving training in careers in solar energy.

Clean Energy Equipment Manufacturing

To promote the development of a domestic supply chain to support a growing clean energy industry, $2.3 billion in ARRA funds were allocated toward a 30 percent tax credit (under IRS Section 48C) to be awarded on a competitive basis. Eligible projects included investments in advanced clean energy manufacturing for a wide range of clean energy products such as equipment for renewable energy generating facilities, energy storage, energy conservation, carbon capture and sequestration, fuel cells, and the refining and blending of renewable fuels. Since nearly all of these involve new technologies with possible innovation spillovers, ARRA is helping to address innovation market failures in multiple areas through these competitively awarded tax credits.

The $2.3 billion program was highly oversubscribed, with interest vastly exceeding DOE expectations. There were over 500 applications, which requested over $8 billion in credits combined. Credits were awarded based on commercial viability, domestic job creation, technological innovation, and speed to project completion.[62] Awards were provided to 183 domestic clean energy manufacturing facilities until the $2.3 billion available was exhausted. These credits were matched by private sector funding of up to $5.4 billion. The success of the program led to another round of competitive funding (Phase II) announced in February 2013 for $150 million in remaining tax credits not fully utilized by previous grantees for projects to be put in service by 2017.

One industry significantly supported by the grants was wind turbine manufacturing. While many factors may have contributed, there was a dramatic increase in the share of domestically-produced wind turbines installed in the United States after ARRA, from 25 percent in 2006-2007 to 72 percent in 2012.[63] The grants also supported energy storage projects. Just as the battery awards described above spurred new battery technologies, Section 48C complemented these awards. Section 48C Phase I and II awards included at least $36 million in credits for battery related manufacturing including mobile charging, advanced battery packs, and intermediate materials and components.

[62] Mundaca and Richter (2015).

[63] EERE (2013).

Appendix II: CEA Calculation of ARRA Clean Energy Spending

This appendix provides an overview of CEA's calculation of the amount of ARRA clean energy funding that was spent by the end of 2015. This spending estimate is used to calculate the number of job-years supported by the clean energy investments in ARRA.

For the calculation, CEA uses the best evidence available on actual ARRA spending from DOE, the U.S. Treasury (UST), and the Office of Management and Budget (OMB) to develop a spending path from 2009 to the end of 2015. All non-ARRA spending is also removed, including any extensions of programs after the ARRA period.[64] Where actual spending is not available, the most recent available forecasts are used. The approach used follows three steps: (1) use forecasts of tax outlays from the UST for tax incentives, (2) add in known spending from the respective sources, and (3) allocate the funds spent in remaining programs.

Step 1. Use Forecasts of Tax Outlays from Treasury

First, CEA uses the forecast of annual government outlays from ARRA tax incentives provided by the UST Office of Tax Analysis for FY 2012.[65] This forecast is then modified as follows:

1. *1603 Cash Grant in Lieu of ITC*
   For the 1603 program, the UST expected outlays are replaced with actual awards provided in the years 2009 to 2015. Following the static budget scoring methodology, the CEA analysis also adjusts for receipts that represent a forecasted reduction in government receipts that occurs elsewhere as a result of the 1603 program. In other words, total outlays over the 2009 to 2015 period are reduced by forecasted receipts from 2009 to 2015.[66]

2. *Clean Energy Manufacturing Section 48c*
   This program was forecasted by UST with outlays of $1.6 billion. However, updated spending estimates indicate that this program actually awarded $2.3 billion in grants to clean energy manufacturers. Thus, the spending path forecast from UST is adjusted for the actual spending of $2.3 billion. In other words, the spending path from UST was pro-rated such that the total outlays sum to $2.3 billion.

[64] The only exception where an extension from the original 2009 allocation is included is the case of the 1603 Cash Grant. In 2010 this program extended the construction start date required for projects to be eligible for the cash grant by one year. Projects that took advantage of this extension are included in the spending estimates.

[65] The CEA (2010) 3rd QR ARRA Update uses Treasury forecast for FY 2011. The FY 2012 shows larger outlays for residential energy efficiency credits. Clean energy subcategories with OTA forecasts of tax outlays include: PTC extension; extension of ITC eligibility; 1603 Cash Grant in Lieu of ITC (modified with program specific details); removal of the ITC cap for small wind; expansion of the residential energy efficiency tax credit; Clean Renewable Energy Bonds; Qualified energy conservation bonds; refueling tax credit; alternative motor vehicle credit; tax parity for transit and parking credits; and Section 48c Manufacturing (modified with program specific details).

[66] Receipts forecasted from UST FY2011 are used here as 1603 outlays were not included in UST FY2012 estimates of tax benefits.

Step 2. Add In Known Spending

For categories with records of funds spent by a given date, the total spending is distributed equally across years before that date. These programs include: the Weatherization Assistance Program (updates from DOE), 1705 Loan Program (updates from DOE), high speed rail and Federal Transit Administration grant spending (updates from FRA and DOT), and the increase in borrowing authority to the Bonneville Power Administration and Western Area Power Administration (updates from OMB).[67]

Step 3. Allocate Funds Spent in Remaining Programs

The majority of the categories remaining after considering the spending categories with tax forecasts and known spending are managed by the DOE. As of May 2013, 82 percent of DOE allocated funds had been spent. As of year-end 2015, 90 percent of allocated funds had been spent. As such, for programs with spending paths not filled in by Step 1 and Step 2 above, a path is distributed equally across years such that 82 percent of the funds are spent by mid-2013. Next, spending is distributed equally across from mid-2013 to year end 2015 is developed such that in total 90 percent of funds are spent by year-end of 2015. Funds leftover after Steps 1 through 3 are assumed not spent over the 2009 to 2015 period.

[67] For WAP the spending path is not uniform: a spending path identified from the DOE PAGE database is used to pro-rate total WAP expenditures reported by DOE (2016a) to develop a spending path from 2009 to 2013.